The TREND IN ENGINEERING

at the University of Washington

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MODEL ANALYSIS OF PAVEMENT STRESSES

A NEW CRITICAL PHASE OF THE LAKE WASHINGTON POLLUTION PROBLEM

HEAT TRANSFER TO LIQUID-SOLID SUSPENSIONS IN TURBULENT FLOW IN PIPES

CERAMIC ENGINEERING AT THE UNIVERSITY OF WASHINGTON: AN ANALYSIS

PRESSURE LINE FOR A TWO-HINGED ARCH RIB SUBJECT TO VERTICAL LOADS

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LIFE AND DEATH OF A LAKE

(Chief source of this material was A. D. Hasler's "Eutrophication of Lakes by Domestic Drainage," *Ecology*, 42, 4, 1948. For original references see bibliography, *op. cit.*)

POPULAR AND SCIENTIFIC CONCERN over such marked biological changes as have occurred in Lake Washington has not been confined to this region nor to recent times. Investigators of 37 lakes in Austria, England, Finland, Germany, Italy, Sweden, Switzerland, as well as in other parts of the United States, have long been reporting serious lake deterioration in some of the most famous resort areas in the world. Records in some cases date back almost a century and may possibly offer us a basis for predicting at least a general trend in our local situation.

Of special interest, perhaps, to Seattle dwellers is the history of Lake Zürich, stretching south and easterly from the city of Zürich, "the Athens of Switzerland." It consists of two distinct basins connected by a narrow (about ½-mile) passage: the smaller, shallower *Obersee* (Upper Lake), of maximum depth 165 feet, and the larger *Untersee* (Lower Lake) immediately south of the city, of maximum depth around 470 feet. The total length of the lake is about 25 miles, with an area of 34 square miles.* The Linz River flows northwestward *into* the Upper Lake; the Limmat river flows in the same general direction *out of* the Lower Lake and bisects the city of Zürich. The city itself thus contributes no drainage to either part of the lake, but urban effluents from a group of smaller communities (110,000 total population) drain into the larger Lower Lake. The Upper Lake receives no major sewage drainage and has maintained its pristine appearance and controlled productivity. The Lower Lake has long been classed as eutrophic, i.e., enriched with nutrients. This fact gives its history an experimental value, its smaller companion being considered a "control."

In 1898, a species of alga, *Oscillatoria rubescens*,† first appeared in the Lower Lake. It had been reported rife in the eutrophic Lake Morat (the *Murtensee*) in western Switzerland for the previous 70 years, but not elsewhere in Switzerland except for one brief sporadic appearance. In the period "before 1910 to 1928" the transparency of the Lower Lake had decreased to "not much more than one-third" of its former condition. Thirty years ago the trout and whitefish disappeared, being replaced by such coarser fishes as perch, northern pike, and "rough fish."

In brief, "less than a hundred years ago both basins were clear, clean, and supported a commercial crop of trout and whitefish." Since the turn of the century, algal scums in the Lower Lake have created a malodorous nuisance, turning the larger part of Lake Zürich and the water of the Limmat as it flows through the city to a copper-red color, and requiring expensive filtering and purifying equipment for the city's water supply.

The case of Lake Morat, cited previously, is the oldest recorded in which *Oscillatoria rubescens* has played the chief part. The local name for this alga is *Burgenderblut* (Burgundy blood) because of the legend that after the Swiss war with Burgundy (1476) the lake was red with the blood of battle.

Other Swiss lakes have undergone a similar transformation. *O. rubescens*, unknown in the *Hallwilersee* (west of Zürich) before 1897, "underwent an explosive development" in 1898. By 1921 the lake was termed "a disappearing glacial lake." In 1907 the *Rotsee* (Red Lake), a small lake near Lucerne, had no *O. rubescens*. In 1910 it "erupted" and the name of the lake was said to be justified by the quantities of this alga which it contained. This "bloom" occurred two years in succession and then had not reappeared up to 1924. Significantly, although the city of Lucerne at great expense stopped domestic pollution of this lake, "reversal of the eutrophication process has not been noticeable (1946)." Another lake (the *Greifensee*) receiving drainage from Lucerne in 1917 was "moderately eutrophic," in 1945, "strongly eutrophic."

While the "explosive development" of *O. rubescens*, often noted, has perhaps given special prominence to this species, it is only one of many algae which, because of uncontrolled productivity, have taken over some of the most beautiful lakes. Ironically, Lake Windermere, the largest lake in England and a tourist literary shrine in the romantic Lake Country, is the receptacle for effluents from increasing urban areas. "Cores" removed from the bottom of the lake show that there was apparently little change in the character of the sedimentary deposits from the end of the Ice Age to comparatively recent times. This change, accelerating with the great increase in tourist population beginning in the 1840's, has progressed rapidly as the area has become a "commuters' suburb of Liverpool and Manchester, 80 miles away." Drainage of both raw and treated sewage has resulted in large "blooms" of blue-green algae and a clouding of the water.

(Continued on page 24)

* The area of Lake Washington is 38 square miles.

† This alga, red in color although classified with the "blue-green" algae, was first noted in Lake Washington in 1955.

University Seeks More Engineering Teachers

A LARGE INCREASE IN ENGINEERING ENROLLMENT at the University of Washington has created an immediate need for 18 additional engineering teachers in the Departments of Electrical Engineering, Mechanical Engineering, and General Engineering. The last named department supervises freshman courses in Drawing, Engineering Problems, Mechanics, etc.

Positions are in the Instructor and Assistant Professor ranks. Salaries will vary from $500 to $650 a month for the school year, depending upon academic background and professional experience.

Although men with graduate degrees are preferred, there are some openings for men with bachelor degrees who wish to pursue graduate study concurrently. Teaching and practical experience are desirable but not essential. Opportunities for advancement are excellent. Summer employment in the Seattle area is virtually assured.

For further information write

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Aerial view of the University of Washington campus where 2100 students are enrolled in the College of Engineering

April, 1956

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FIG. 1. THE AUTHORS WITH THEIR MODEL OF A HIGHWAY TEST TRACK. *Left to right:* Mr. La Cross, Professor Ekse, Mr. Danielson.

MODEL ANALYSIS OF PAVEMENT STRESSES

DON H. DANIELSON LEON M. LA CROSS
Research Assistants in the Engineering Experiment Station

MARTIN EKSE
Associate Professor of Civil Engineering

DURING RECENT YEARS, the rapidly growing need for a more adequate highway system has added incentive to private and federal agencies to improve the quality as well as the quantity of new highways. In order to do this, methods of testing load and wearing characteristics of subgrade and pavement need to be evaluated.

One method deals with the construction of full-sized test roads such as the Western Association of State Highway Officials (WASHO) test loops near Malad, Idaho. Although the WASHO series of tests has yielded much valuable information,* it also revealed certain disadvantages of the method. Chief among these was the great cost: the WASHO test road project cost nearly a million dollars. Lack of control of the weather and of soil conditions at the test site were other unfavorable factors.

Another method of evaluating subgrade and pavement characteristics is through tests on models. Attempts in this direction have usually made use of circular tracks. A typical example is a track built in 1934 by the Bureau of Public Roads at its Arlington Experiment Farm.

This track consists of an annular concrete trough, 12 in. deep, 18 in. wide, and 12 ft in diameter measured at the centerline. Another trough 3 in. wide and 13 in. deep runs along the smaller circumference of the main trough and is used as a reservoir for the introduction of water into the base material under the test surfaces through small openings at the base of the partition.

The traffic load is applied by two full-sized automobile wheels fixed on the two ends of a rigid structural member. This member is rotated in a horizontal plane by a vertical shaft in a pedestal at the center of the track. An electric motor operating through a 3-step cone pulley and a worm reduction drives the vertical shaft at the center of the track.

This circular type of test track has two disadvantages: (1) the large size of the track demands much soil to build up the subgrade and (2) the constant lateral acceleration of the wheels on a circular path tends to rut the surface.

Although several versions of the circular test track have been constructed, they have not avoided these difficulties, which seem to be inherent in the basic design.

* *The WASHO Road Test*, Highway Research Board Special Report No. 22, 1955.

The project being carried on at the University of Washington, with which this paper deals, sought another approach to the model test track principle. The disadvantages of a full-sized test track, it was thought, could be eliminated by designing a device capable of applying a variable load at a variable speed. This load would be transmitted to the reduced highway subgrade and pavement by pneumatic tires rolling along a straight path. By building the unit indoors, the climate and moisture could be easily controlled. To combine these design criteria into a practical and dependable machine, however, was the real problem.

Since the approximate average diameter of a truck tire is 36 in., a convenient scale ratio of three was adopted, giving a model-tire diameter of 12 in., and establishing a linear scale to be used in later scale theory development.

The variable speed of the model tires could be attained either by using a sort of transmission in the power train of the machine or by having a motor with a variable speed device incorporated into its construction. The latter device was adopted.

The simplest means of varying the load applied to the pavement through the tires seemed to be by placing a number of coil springs at specific points about the loading assembly, and mounting them so that they would react against a framework. This framework would be mounted on the tank which would hold the actual material to be tested.

If the wheels were to roll in a straight path instead of a circular one, as in previous test tracks, some type of return had to be used to get them back to their starting position. An endless chain, used to make load repetitions in large numbers possible, solved the problem by raising the returning wheels and tires above the levels of the wheels and tires actually running on the test surface.

The fundamental layout of the test track is shown in Fig. 1.

The tank is a chest type of refrigerator acquired as war surplus. It is insulated and has water outlet fittings. These features will be very useful when tests are conducted on frozen and saturated subgrades.

The loading apparatus (Figs. 2 and 3), a spring assembly located in each of the four corner angles, was designed to apply a direct load to the main shafts. Each assembly consists of a large roller

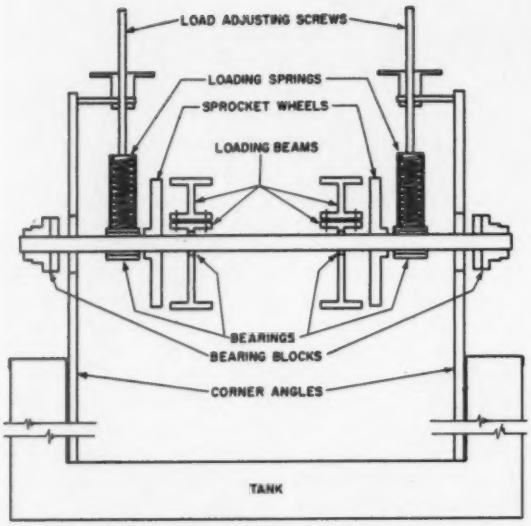

FIG. 2. CROSS SECTION THROUGH MAIN SHAFT OF THE MODEL

bearing running on the main shaft, housed in a 3-in. cube of steel. To the top of the cube, a length of 2½ in. pipe is welded in an upright position to enclose the coil spring, which actually does the loading. A plunger type of arrangement, consisting of a round plate on a ¾-in. threaded shaft, moves up and down in the pipe, applying a load to the spring. The threaded shaft can be screwed up or down by means of a large cylindrical nut with handles, mounted on a plate welded to the corner angle.

The corner angles are slotted for vertical movement of the main shafts and drilled for mounting bolts. The plate guides in which the bearing blocks slide are welded to the corner angles. The four complete assemblies are bolted into the four corners of the tank.

The calibration of the loading springs and the effects of different tire pressures were determined on a plank surface, constructed in the tank.

The highway test track, now ready for subgrade and pavement construction, will be the predominant feature of a comprehensive research program due to get underway during the next few weeks.

A highway subgrade will be constructed in the tank to simulate a large portion of the nation's highways. The soil to be used in the first test subgrade is a silt, which is typical of the soil used in many roads which have failed to bear modern traffic. By choosing such a soil, failure can be induced under more or less controlled conditions. The various factors contributing to such failure can thus be separated and studied individually.

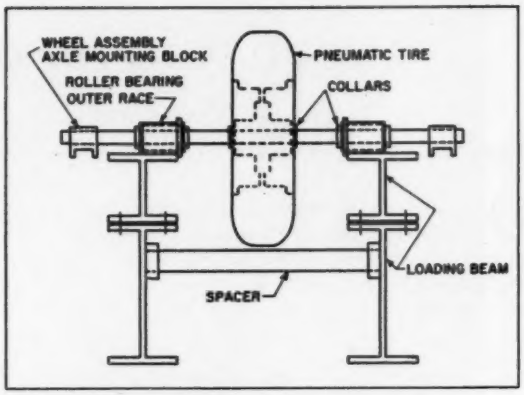

FIG. 3. WHEEL SHAFT ASSEMBLY

As in any basic research, a measurement standard, which can be used and compared in all related tests, must be established. It is believed that the basic measurement of the effect of a load on any particular soil is the distribution of pressures within the soil mass. An accurate and reliable pressure-measuring device, or pressure cell, is of course, essential. The cell must be small enough so that pressures are not unduly affected by the cell itself.

Of the several attempts in the past to measure earth pressures, some have been quite successful under certain conditions. However, the cells which have been developed previously are not adapted to the present scale-model project either because of their size, or the measurement procedure, or the cost.

A hopeful approach to measuring pressure seems to be through the use of a material whose electrical conductivity is affected by pressure, such as carbon. Recently a commercial product has been developed for use in pressure-measuring instruments which has an advantage over carbon in that it is relatively incompressible, and therefore more consistent. Preliminary tests indicate that this type of device is a good possibility.

Upon establishment of suitable instrumentation and measurement techniques, pavement deflections and the variance in soil-pressure distribution will be studied under various conditions of pavement thickness, subgrade moisture, and soil types.

Although the thickness of asphalt paving has a more definite relationship to dynamic load capacity than to static load capacity, present design procedure has not fully considered dynamic loads. However, highways are subjected to dynamic loads almost exclusively, and future design criteria based on an investigation of internal pressures due to such loads may prove more realistic than those of the past. This test tract is especially well suited to such investigation.

A research program, continuing perhaps for several years, can deal with the effects of such variables as soil type or classification, moisture content, temperature, load intensity, and load frequency. Different combinations of such variables are infinite, but all can be controlled within practical limits. Both asphalt and concrete pavements can be tested with these variables and, by correlating all tests on the basis of the internal soil pressure distribution, a comparative analysis can be made for any type of pavement, under any known conditions.

Data compiled during recent full-scale road tests indicate a vital need for more basic highway research. The test track at the University of Washington can help provide much information to verify or supplement the conclusions drawn from full-scale tests. It can also indicate methods and procedures which would be useful on future full-scale tests. This basic research will continue to improve the adequacy and economy of highway pavement design—factors especially important now, in view of the nation's accelerating highway program.

New Transportation Text Reviewed

FUNDAMENTALS OF TRANSPORTATION ENGINEERING: Robert G. Hennes, Martin I. Ekse. McGraw-Hill Series in Civil Engineering. 1955. 520 pages. $8.50.

The authors in the preface to this text book state that it is their intent to combine in one volume the treatment of several types of transportation engineering. In the opinion of these reviewers they have successfully accomplished their aim.

The text is written with exceptional clarity and can be readily understood by anyone interested in the subject of transportation. The illustrations and charts add to the readability of the text. At the end of each chapter is a list of questions and problems that aid the reader's understanding of the material, and a bibliography of suggested material for further study.

The text is divided into four major divisions: Road and Pavements, Airport Engineering, Railroad Engineering, and River and Coastal Engineering; and two minor divisions: Pipeline Transportation and Belt Conveyors.

Part 1, Roads and Pavements, includes chapters on foundations, preparing the road bed and drainage, and a number of chapters that treat of the various types of pavement.

The chapter on foundations shows the application of the science of soil mechanics to foundation problems; the chapter on drainage stresses the importance of drainage in prolonging the life of pavement. The chapter on grading overlaps to some extent the chapter on foundations in that it shows the supporting capacities of the different types of soil, but gives, in addition, methods of improving the foundations by compaction and the removal of peat and muck. The chapters on pavements deal with (1) the cheaper types of road: soil stabilized road, sand-clay, gravel-surfaced road, etc; (2) the intermediate type of road, i.e. bituminous road mix, etc.; and (3) the high-type bituminous and Portland-cement concrete pavements. Methods of testing the materials used in all the types of pavements are described, as well as pertinent factors that need to be evaluated in determining the type of pavement to be used. The final chapter in this division deals with maintenance of streets and roads and with the savings that can be made by proper maintenance.

Part 2 of the text, Airport Engineering, deals with airport planning and design standards, as well as grading, drainage, pavement, and marking and lighting.

In the chapter on airport planning the authors point out the importance of aircraft as a means of transportation and include a number of tables that show the rapid growth of this type of transportation and also give the probable number of airplane passengers in future years.

The chapter on design contains tables showing required runway lengths needed for the different types of air craft, the relationship between the direction of the prevailing winds and the direction of the runway, and the allowable vertical height of obstructions near the airport. The chapter on pavements adds little to the material covered in the section on highway pavement in Part 1; however, the grading of large areas, such as airports, and similarly the drainage of these large areas introduces some problems not met in connection with the relatively narrow highway sections. Methods of attacking these problems are covered in the chapters on grading and drainage. Worthy of special mention are the drawings showing the different types of drainage structures. The final chapter of Part 2 of the text, dealing with marking and lighting, indicates the accepted methods developed by the C.A.A. Again, the illustrations add much to the value of this chapter.

Part 3 of the text, dealing with railroad engineering, in the opinion of these reviewers, is the best section of the book. The authors seem not only well

(Continued on page 32)

A New Critical Phase of the Lake Washington Pollution Problem

R. O. Sylvester

W. T. Edmondson

R. H. Bogan

Recently Lake Washington has shown a large increase in biological productivity that will surely affect to some extent the usefulness of the lake for purposes of recreation and water supply. Moreover, a change in the kind of organisms present suggests that the Lake is already well along in the process of deterioration. Effective action to counteract these changes must be based on full knowledge of the extent and cause of the changes. Moreover, action, to be effective, must be taken soon, before a degree of change has been reached that would require many years to overcome. The biological situation, recently reported by Dr. Edmondson of the Zoology Department at a meeting of the Seattle A.S.C.E., has sparked plans for an Experiment Station project to study the problem. Several aspects are being presented here by University authorities in fields affected.

A Paradox of Water-Pollution Control

R. O. SYLVESTER

Associate Professor of Sanitary Engineering

LAKE WASHINGTON IS ONE OF THE CHIEF ASSETS of Metropolitan Seattle, an asset that has merited the concern of responsible citizens since the founding of Seattle. As a source of beauty, recreation, and as a site for homes along its shoreline, it can hardly be surpassed. Its waters have served both to provide and to obstruct transportation. They have furnished water for water supply and at the same time acted as a receptacle for waste or unwanted waters.

Lake Washington is some 22 miles in length, has a water area of about 38 square miles and a shoreline of approximately 51 miles, of which 20 are within the Seattle City limits. A metropolitan area of about 157 square miles in King and Snohomish Counties drains naturally to Lake Washington.[1,2] This area has a present estimated population of 108,000 persons (exclusive of Seattle) and a predicted future population of 277,000 persons.[1,2] It is interesting to note that 73 square miles of rapidly developing territory in Snohomish County, having a present population in excess of 40,000 persons and commencing at a point two miles south of Everett, drains southward into King County and into the north end of Lake Washington.[2]

Seattle commenced discharging raw sewage into Lake Washington around the turn of the century.[3] As the city grew, more and more sewage was discharged to the Lake from an increasing multiplicity of sewer outfalls. Renton and Kirkland soon installed sewers and commenced their sewage discharge into the Lake. Bathing beaches along Seattle's lakeshore enjoyed an increasing popularity, while at the same time the untreated sewage discharge was increasing. This created such an intolerable condition that in 1926 a bond issue was voted in Seattle for a series of intercepting and trunk sewers to divert the sewage from Lake Washington to a treatment plant on the lower Duwamish River. In 1941 this project was completed with the removal of the last outfall sewer into Lake Washington from Seattle.

Interception of these outfall sewers did not completely solve the sewage discharge problem insofar

as Seattle was concerned, because the City has a combined sewer system, i.e., a single pipe serves both as a conveyor of sanitary sewage and as a conveyor of storm water. Storm water flows may be large, and it is not economically feasible or possible to pump and transport this large combined flow all the way to Puget Sound. These combined sewers therefore overflow into Lake Washington whenever there is an appreciable rainfall, carrying into the Lake a mixture of sanitary and storm sewage. Figure 1 shows the location of 32 sewer overflows to the Lake.

With the military buildup commencing in 1940, water pollution became acute in the vicinity of the Naval Air Station, Renton, and Kirkland. In 1941, sewage-treatment plants were placed in operation at the Sand Point Naval Air Station and at the Sand Point Housing Project.[4] In 1942 two more sewage-treatment plants went into operation, one serving the Renton-Boeing plant, and the other the Naval Hospital north of Seattle. Renton and Kirkland both completed treatment plants in 1943. The acute conditions of raw sewage discharges to the Lake were now corrected. The Lakeridge Housing Development placed a sewage-treatment plant in operation in 1945, Shorewood on Mercer Island in 1948, Bryn-Mawr Lakeridge in 1951, Lake City Sewer District in 1952, and Bellevue and East Mercer in 1953. Plans for a treatment plant serving the north end of Mercer Island have been completed. All of these sewage-treatment plants are capable, when not overloaded, of producing a highly treated effluent. Figure 2 illustrates the increase in sewage discharge to the Lake during the past 20 years.

The first major sanitary engineering study of Lake Washington water quality was conducted in 1942-43,[4] the second in 1945,[5] and the third in 1952.[6] Limnological studies have been made in 1933, 1950, and 1955.

The chief sources of pollution to Lake Washington are now (1) the north end where Lyons and McAleer Creeks and the Sammamish River discharge polluted water to the Lake; (2) overflows of combined sewage from the Seattle sewer system; (3) leaching from septic tank drainfields serving an estimated 60,000 persons bordering the Lake in unsewered areas,* and (4) the overloaded Lake City Sewer District treatment plant.

Secondary sewage-treatment plants, like those discharging to Lake Washington, make waste water discharges perfectly acceptable from a health, aesthetic, and fisheries standpoint. The paradox of this entire water-pollution control picture is that, even with complete or secondary (biological) sewage treatment, we still have a detrimental effect from

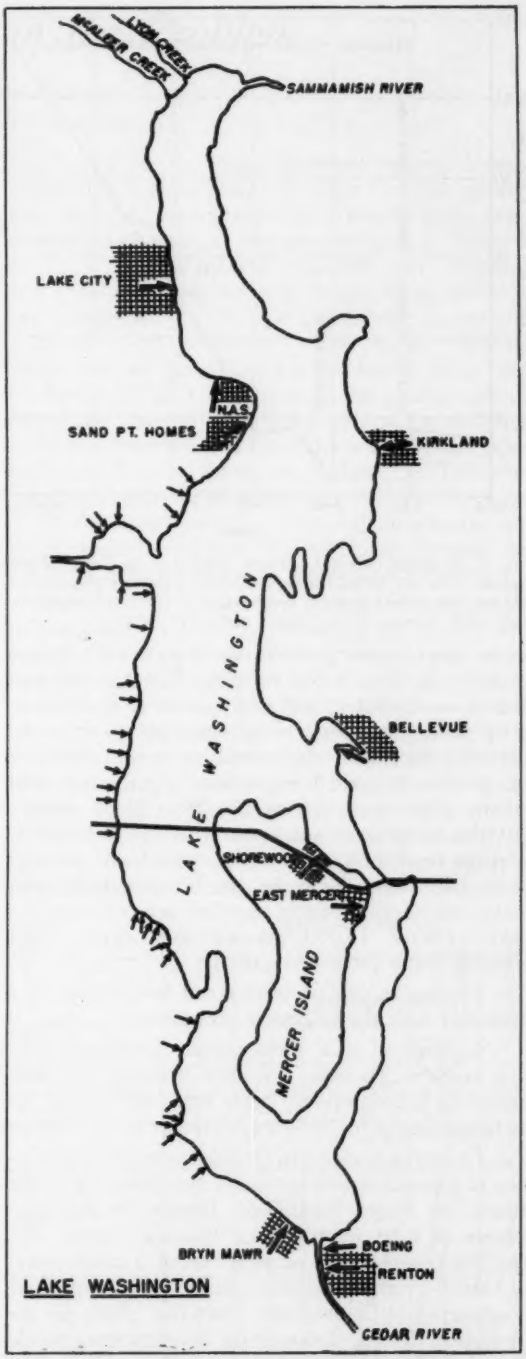

FIG. 1. OUTLINE OF LAKE WASHINGTON, SHOWING MAJOR POINTS OF ENRICHMENT.

The 32 light arrows denote sewer overflows from the Seattle system. The 10 heavy arrows show points at which treated sewage effluents are discharged into the Lake.

* The soil around Lake Washington is generally poor for subsurface sewage irrigation, and the septic tank effluents must therefore eventually drain into the Lake waters.

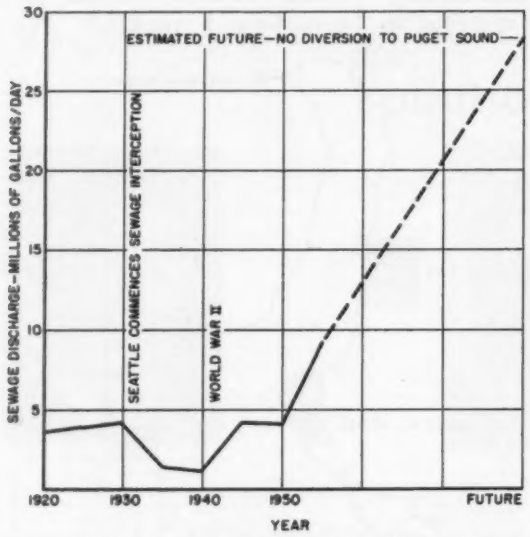

FIG. 2. Estimate of total sewage discharge to Lake Washington. Data are based on an estimated tributary population 100 gal. per capita per day discharge. *(Tributary populations from U.S. Census Reports and historical data.)*

waste water discharge that may cause a very serious nuisance in the Lake waters. Sewage, whether treated or untreated, will add quantities of fertilizer to the Lake in the form of nitrogen, phosphorus, and mineral compounds. This fertilization will stimulate the growth of rooted vegetation, algae, and other aquatic plant and microscopic life. These aquatic growths, when luxuriant, are detrimental in that they limit the recreation usage of the water body, produce odors when they decay on the beaches, and cause tastes and odors in water supplies derived from the Lake. (Some 15,000 persons now derive their drinking water from the Lake.)

A solution to this problem could involve one or a combination of the following procedures:

1. Formation of a metropolitan sewerage planning agency. To date, sewerage planning has been largely on a hodge-podge basis with little regard for anything but the immediate area requiring facilities.

2. Conversion of existing sewage-treatment facilities to primary treatment units and pumping of the effluent to Puget Sound for dilution in the large volume of tidal waters. The Bellevue Sewer District has proposed the construction of a trunk sewer to extend from Houghton southward along Lake Washington to a proposed treatment plant on the Duwamish River. Intervening developments would all connect into this multimillion dollar project. The complete elimination of sewage discharge to Lake Washington is a method of preventing aquatic growth damage to the Lake, but one that will be many years in its ultimate realization. This discharge must be eliminated, however, before nutrient addition has reached the point that algal blooms become a real nuisance.

3. Research on the relationship between Lake Washington water temperatures, algal growth, and the nutriments furnished to water by domestic sewage. While diversion of treatment-plant effluent from the lake could reduce the problem, other methods should be investigated. It is possible that this research might indicate that, if the phosphate content of the water could be kept below a certain limiting value, algal growths would not be any more severe than they have been in the past. Practical and effective methods for phosphate removal from treated sewage effluents common to this area would have to be demonstrated. If this research proves fruitful, a method will then be available for aquatic plant control in the Lake which can continue in use until such time as funds can be made available to carry the area's waste waters to Puget Sound for disposal. (This possibility of nutriment reduction should not, however, be considered as a substitute for the Bellevue Sewer District's plan to intercept east-side flows and carry them to the Duwamish River for disposal.) The University's Zoology and Civil Engineering Departments are tentatively planning this research to be performed as an Engineering Experiment Station Project.

The next section of this paper explains the biological changes that have been taking place in Lake Washington since the continuing introduction of more and more waste waters and also speculates on what may happen to the water quality if this fertilization continues to increase as thousands of new homes are built in the Lake Washington drainage basin. The third section explains the sanitary chemistry involved in the conversion of domestic wastes to aquatic fertilizer and discusses possible means of removing these fertilizing substances.

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Biological Aspects of the Problem

W. THOMAS EDMONDSON
Associate Professor of Zoology

AS INDICATED IN THE FOREGOING SECTION, the effluent from sewage-treatment plants contains substances which are important as nutrients for plants, chiefly phosphate and nitrate. The response of the plants in the lake to increased nutrition is comparable to the response of a lawn when fertilized; the plants grow faster and larger quantities are produced. In other words, the productivity of the lake is increased.

To describe fully the modern concepts of the biological productivity of a lake would require more space than is available here. It may be pointed out, however, that the most important primary productive process is that of photosynthesis, by which plants produce carbohydrates from carbon dioxide and water, using sunlight as the source of energy. The carbohydrate so constructed is rich in energy, which is available for the life processes of the plants. In addition to carbon dioxide, of course, plants require a great variety of chemical substances, some of which are often in such short supply that they regulate the rate at which production can proceed. Nitrogen and phosphorus are very often limiting factors. The plant material itself is eaten, digested, and assimilated by animals as their source of energy and material. These animals in turn are used as food by others. Thus, the production of animals is based mostly on photosynthetic production of plants.

Most of the plants in Lake Washington are microscopic or very small floating algae which are found in all regions of the lake in the upper waters. A dense population of algae gives the water a cloudy appearance, reducing its transparency. An extremely dense population of algae is often referred to as a "nuisance bloom." There is nothing inherently dirty or repulsive about algae, but some of the results of the bloom are unpleasant. In the first place, water containing a bloom is not pleasant to swim in, for when the water dries on the skin and in the hair a sticky layer of plant material is left. During calm weather quantities of the material may float to the surface and later be blown down-wind to the shore where it may accumulate in decaying layers on the beaches. The odors associated with algae decaying either on the shore or in the water may be extremely unpleasant and render the water useless for swimming, boating, and drinking. Thus, real estate values may be affected.

There is still another consequence of the increase in biological productivity following enrichment with sewage. To understand this, it is necessary to realize that during the summer the lake has a layer of warm water floating on top, effectively sealing off the bottom part of the lake from contact with the air (Fig. 3A, 3B). Since the bottom part of the lake is populated by animals, bacteria, and fungi, which require oxygen for their life processes, the oxygen content of the bottom layer decreases steadily during the summer. In that part there is not enough light for photosynthesis. Because the population of organisms

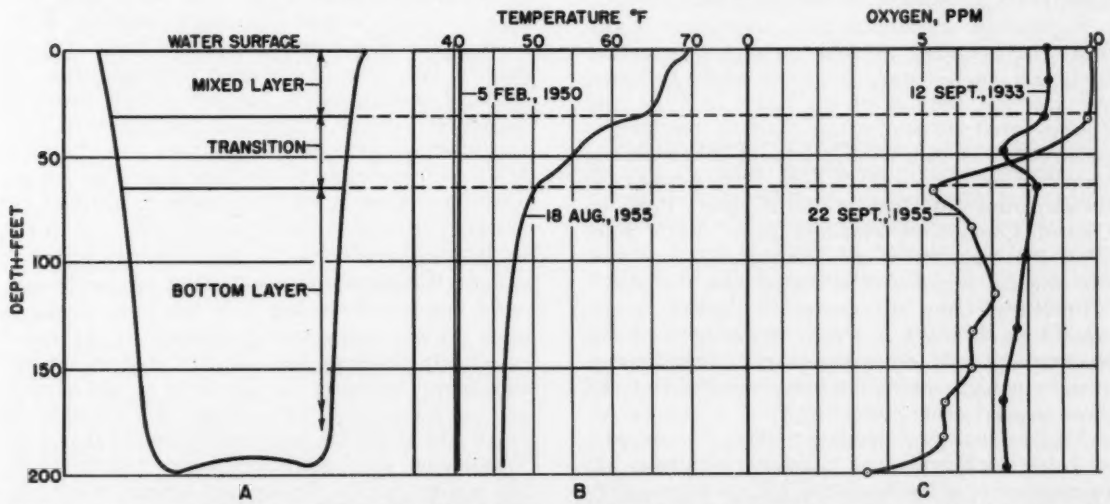

FIG. 3. A. Vertical section through Lake Washington, east from Madison Park, showing summer stratification. The width of the lake is about 1.6 miles at that point. B. Typical vertical distribution of temperature in the lake during summer and winter. C. Vertical distribution of oxygen concentration toward the end of summer, 1933 and 1955.

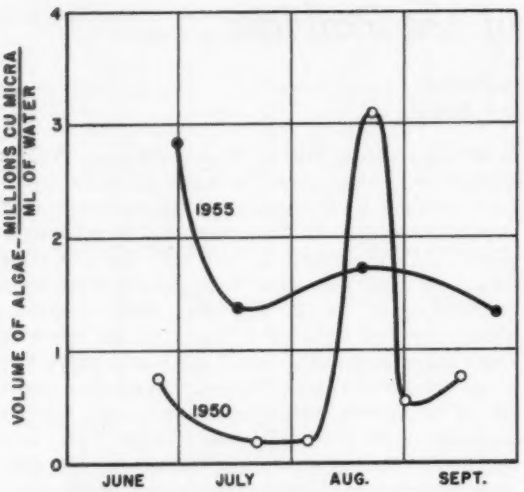

FIG. 4. Abundance of algae in the mixed layer of Lake Washington during the summers of 1950 and 1955.

in the bottom part of the lake depends upon organic material coming from above, the rate at which oxygen is removed from the lower layer is, to some extent, a measure of the productivity. In a very productive lake, the oxygen may be completely used up, and odorous hydrogen sulfide may accumulate.

For some game fish, which require both low temperature and relatively high oxygen concentration, the bottom part of a productive lake may be uninhabitable during the summer. The effect of enrichment on the fish population of a particular lake, however, will depend on the requirements of the species present. Some may be encouraged by increased food supply, others, damaged by lack of sufficient oxygen.

Fortunately, scientists at the University of Washington have studied the lake on several occasions. In 1933 a detailed study was made of the biological and chemical features of the lake. In 1950, two Zoology graduate students worked on the lake in connection with their Ph.D. theses. (This work was supported by Initiative 171.) In 1955, members of the Department of Zoology and the State Pollution Control Commission obtained more data. Since 1950, the Department of Oceanography has been studying the intrusion of salt water into the lake.

Currently, Lake Washington is showing an increased productivity, evidently resulting from the fertilization with treated sewage. The average quantity of algae during the summer of 1955 was 1.8 times as great as in 1950 (Fig. 4).

Another biological indication that the character of Lake Washington has changed profoundly was the appearance in the summer of 1955 of large quantities of the alga, *Oscillatoria rubescens*. This particular alga makes large populations in many enriched lakes, and is a notorious nuisance in parts of the Middle West of the United States and in Switzerland. While this species can live in a variety of lakes, its frequency in polluted lakes seems to indicate conditions in which odor nuisances can develop, and makes its sudden appearance here of great interest.

The rate of oxygen consumption in the bottom layer during the summer has increased greatly during the past 22 years. In 1933, 825 tons of oxygen were removed per month. In 1950 the rate was 1400 tons per month. In 1955 the rate was 2190 tons per month, which is 2.7 times the 1933 value (Fig. 5).

Also of biological interest is the concentration of oxygen. (See Fig. 3C.) In 1933 the minimum oxygen concentration reached, near the bottom of the lake, was 6.4 ppm. In 1955 the minimum concentration was 3.5 ppm. Although there was a much larger concentration of oxygen in the upper part of the hypolimnion, it may be expected that, if the present trend continues, much of the lower layer in time may become nearly devoid of oxygen during the summer.

The quantity of inorganic phosphate in the lower layer increases during the summer, concurrently with the decrease in oxygen. The major source of this phosphorus is the organic material falling from above, and the release is caused by the activity of animals and bacteria in the bottom. During fall and winter, the entire lake is mixed from top to bottom by the wind and this phosphate is then available for re-use by the algae. In 1933 the maximum concentration of inorganic phosphorus ever observed was 0.025 ppm, while in 1955 it was 0.038. Biologically, this is a very significant difference.

To make a complete assessment of all the sources of nutrition coming into the lake now would be a very time-consuming and expensive operation. However, in view of the great increase in human population of the Lake Washington drainage area, the domestic sewage inflow has undoubtedly increased during the past few decades. It does not seem likely that other sources, such as drainage from fertilized fields, have increased to the same degree as sewage. Therefore, it seems very reasonable to attribute the observed increase of nutrients in the lake and, hence, the increased productivity, to an increase in sewage.

Lake Washington is not the first lake to be seriously enriched by sewage. It has been shown in other regions that domestic drainage is capable of profoundly changing the character of lakes through well-known processes; in fact, it is an old story in parts of this country and Europe. For instance, the lower lake at Zürich, considerably deeper than Lake Washington, was a good trout-fishing lake during the last century, but the development of many small communities around the shore of this lake resulted in enrichment, and in 1898 *Oscillatoria rubescens* made

an abrupt, explosive appearance. Since that time the lake has lost its trout population, and the bottom water becomes devoid of oxygen during the summer. Some of the lakes near Madison, Wis., are fertilized by both domestic and agricultural drainage, and have been producing nuisance blooms for many years.

There is no reason to expect the development of Lake Washington to take a different course from that of similar enriched lakes, so long as the present disposal of sewage continues. Only by decreasing the flow of nutrients to the lake, or preventing the growth of algae by other means, can the consequences be avoided. To make any change will be expensive. To make no change will result in a lessening of the usability of the lake. Obviously, it is necessary for the community to make a choice.

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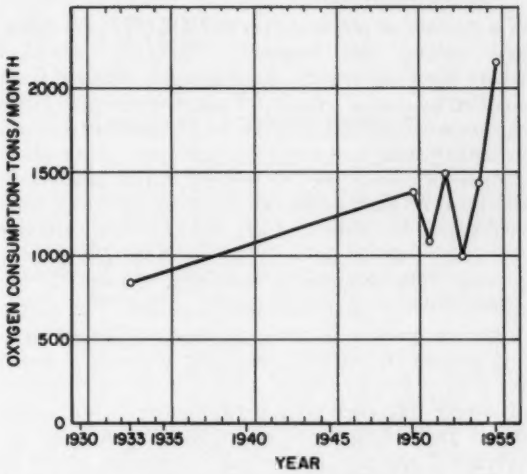

Fig. 5. Rate of oxygen decrease in lower layer of Lake Washington during summer. Note the sharp rise in this rate in 1955. Data do not exist to permit explanation of the small variations between 1950 and 1954.

Treatment and Control of Nutritional Elements

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Early Concepts

Domestic eutrophication of lakes has been recognized for many years. However, attempts to remove the fertilizing matters present in most sewages through the application of specific treatment processes are of relatively recent origin. The belief is prevalent in some quarters that all that is needed to correct the situation is to incorporate a system of sewage treatment to relieve such waters of their fertilizing constituents. Unfortunately, sewage treatment as practiced today is essentially a mineralizing process. During treatment organic substances are broken down to release nitrogen as ammonium compounds and to liberate phosphorus as phosphate compounds. Consequently the effluent from sewage-treatment plants contain much more readily available fertilizer than do raw wastes.

Extensive investigations[1,2] indicate that the most promising means of controlling algae blooms is to remove phosphates from phosphorus-rich wastes. Recognition of the significance of phosphorus focused the attention of research workers during the 1940's on the problem of removing this element from industrial and domestic wastes. It was soon found that the form in which the phosphorus was present in a waste has a considerable bearing on its behavior during treatment. Unfortunately, phosphorus is present in most sewages in several different chemical forms each of which responds differently to various treatment processes. This obviously complicates matters. For convenience, the principal forms of phosphorus generally encountered may be classed as organic compounds, complex polyphosphates such as $(NaPO_3)n$, and simple inorganic phosphate ($PO_4^{\equiv}$) salts.

During recent years there has been a considerable increase in the normal phosphorus content of domestic sewages, most of it due to the rapidly expanding use of household synthetic detergents containing large amounts of complex polyphosphate builders. At the present time the phosphorus content of typical domestic sewage averages approximately 4 to 6 mg per liter. Most of this phosphorus is in the form of polyphosphates. The significance of this phosphorus concentration is perhaps better appreciated when it is recalled that a concentration of 0.01 mg per liter is considered to be capable of supporting prolific algal blooms.[1] With this brief review of the phosphorus composition of sewage as a background, let's take a look at the methods of phosphorus removal that have been studied.

Removal of Phosphorus from Sewage

Sewage treatment as normally practiced consists of a number of physical operations such as screening and settling, and frequently biological processes where dissolved organic impurities are removed from solution by special cultures of microorganisms. Little can be accomplished in terms of phosphorus removal in settling tanks and screening chambers. Some phosphorus, of course, may be present in raw sewages in the form of particulate matter, some of which may be removed by settling. Such removals rarely account for more than 2 per cent of the total phosphorus present. The situation is somewhat different in the case of the biological treatment processes. The microorganisms present in these processes utilize nitrogen and phosphorus in their metabolic activities in much the same manner as algae. Owen[3] in an investigation of sewage-treatment plant performances in Minnesota found that phosphorus removals ranged from an average 2 per cent for primary treatment plants to 46 per cent for some plants employing biological treatment. To be effective in removing phosphorus from sewage a process must be capable of tying up soluble phosphates. Accordingly, research workers have turned to a study of biochemical processes and to an investigation of chemical coagulation methods.

Biological Methods

A number of efforts have been made to take advantage of the biological fixation of phosphorus in various types of biological reactors. Under laboratory-controlled conditions complete removal of phosphorus has been achieved. Sawyer[4] has shown that complete removal of phosphorus is possible by the activated sludge process if sufficient carbonaceous food material is present. Similarly, experiments with algal cultures have shown some promise. Plant-scale studies up to the present time have been inconclusive. However, successful application of the principle of biological fixation would provide an extremely effective and highly economical method of phosphorus removal. Development of such a process is now largely an engineering problem.

Chemical Methods

To date the most promising results have been achieved with chemical coagulation processes. Rudolfs[5] has reported on the removal of phosphates from sewage with coagulation using lime. Subsequent studies by Owen[3] and Sawyer[4] indicate that the total soluble P content can be readily reduced to about 0.5 mg per liter. Ferric salts and aluminum sulfate (alum) have also proved effective in removing soluble phosphorus from solution. Typical performance data using alum as the coagulant are shown in Fig. 6. Current research efforts are directed largely at the development of a continuous flow process employing alum, Na_2CO_3, and lime. The findings of

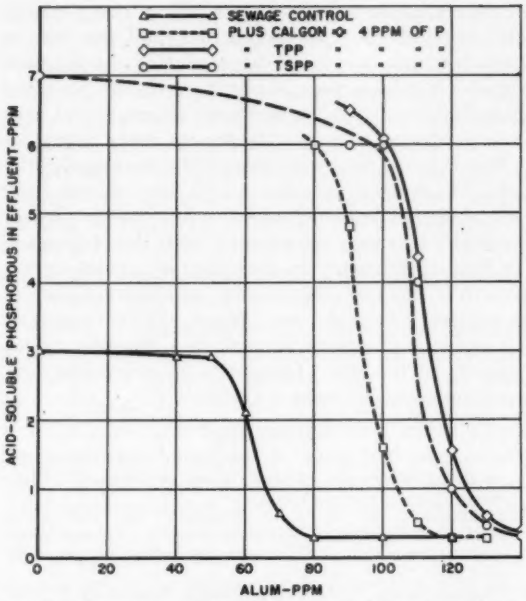

FIG. 6. REMOVAL OF PHOSPHATES FROM SEWAGE BY ALUM COAGULATION. (After C. N. Sawyer[4].)

Rohlich *et al.*[6] at the University of Wisconsin show considerable promise for the alum coagulation process.

In summary it can be said that several promising methods of phosphorus removal have been proposed. Where eutrophication of lakes has become a problem, the economic feasibility of treating domestic and industrial wastes to control their phosphorus content can be ascertained by pilot-plant studies. In many situations costly investments have already been made in extensive sewage-treatment works. The question might logically be asked as to whether it would be advisable to abandon such works for a costly sewerage system or to modify the existing works to remove additional amounts of phosphorus.

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HEAT TRANSFER TO LIQUID-SOLID SUSPENSIONS IN TURBULENT FLOW IN PIPES*

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ALTHOUGH A WEALTH OF DATA is available in literature for the heat-transfer characteristics of single-phase liquids very little is available on heat transfer to heterogeneous systems. Recently, the development of such processes as, for example, catalytic cracking for the production of high-octane gasoline in the petroleum industry, has stimulated a rising interest in fluid and fixed-bed reactors involving heat transfer to gas-solid and liquid-solid systems. For this reason a study of heat transfer to liquid-solid systems was undertaken.

Fluid Characteristics of Suspensions

In order that the heat-transfer coefficients for suspensions may be considered, a brief discussion of the flow of suspensions is desirable. Numerous investigators have found that data for all liquids and suspensions following the principle of Newtonian flow may be correlated, using the conventional friction-factor versus Reynolds-number plot. In general, non-Newtonian fluids behave in the turbulent flow region as Newtonian fluids. That is, the apparent viscosity is constant for a non-Newtonian suspension in the turbulent region.

Caldwell and Babbit,[1] investigating the flow of clay and sewage suspensions (Bingham plastics) in turbulent flow, found that the data correlated with a friction-factor versus Reynolds-number plot when the viscosity of the dispersing medium and the density of the mixture were used in the correlation. For the turbulent flow of pseudoplastic GR-S lattices, Winding, Bauman, and Kranich[2] found that a good pressure-drop correlation was obtained by using the limiting viscosity at infinite shear. Wilhelm, Wroughton, and Loeffel[3] found that, for cement-rock-water suspensions in turbulent flow, the apparent viscosity was higher than the viscosity of water. Treating the suspensions as liquids with pseudo properties, they found that their data could be represented on the friction-factor plot for pure liquids.

For the case of pure liquids, investigators have shown a definite relationship between the amount of heat transferred and the type of flow existing in the pipe. Since the transfer mechanisms for both fluid flow and heat transfer are a function of the wall film, and since fluid flow for pure liquids and suspensions in turbulent flow may be correlated by similar means, the assumption that the correlation for heat transfer of pure liquids might be applied to suspensions in turbulent flow does not seem unreasonable.

Heat Transfer Coefficients

The coefficient of heat transfer by conduction and convection is controlled by the same variables in the differential equations for both momentum and heat transfer. The variables are h, D, k, C_p, G, and μ. For the case of turbulent flow in a circular pipe, dimensional analysis shows that they are related in the following manner:

$$\frac{h_i D}{k} = \phi\left(\frac{DG}{\mu}\right), \left(\frac{C_p \mu}{k}\right).$$

The relationship of the first group with each of the others may be determined experimentally. Dittus and Boelter[4] experimentally determined the relationship between the groups and presented the following equation:

$$\frac{h_i D}{k} = 0.023\left(\frac{DG}{\mu}\right)^{0.8}\left(\frac{C_p \mu}{k}\right)^{0.4}.$$

For Reynolds numbers over 10,000 this equation is accurate within ± 20 per cent for heating a wide variety of homogeneous fluids with viscosities not more than twice that of water. In the light of the foregoing discussion, the same variables should be considered in a dimensional analysis of heat transfer to suspensions in turbulent flow, provided that the major resistance to heat transfer exists in the film on the pipe surface.

The present study is concerned with the heating of graphite-water and graphite-kerosene slurries in a 1-in. copper pipe with condensing steam outside. In such a case heat transfer occurs through three resistances in series: the condensing vapor film outside the pipe, the pipe wall, and the liquid film. In order to determine the coefficient of heat transfer between the pipe wall and the slurry, a knowledge of the outside steam-film resistance or the pipe-wall temperature is essential. Wilson[5] proposed a method whereby a plot is made of the reciprocal of the heat-transfer coefficient versus the reciprocal of the velocity of the fluid to the eight-tenths power. This

* Condensed and arranged from the Ph.D. thesis of Aven P. Miller (1953) by Ramesh C. Vasishth, Teaching Fellow in Chemical Engineering. The research was carried out under the supervision of Dr. Moulton.

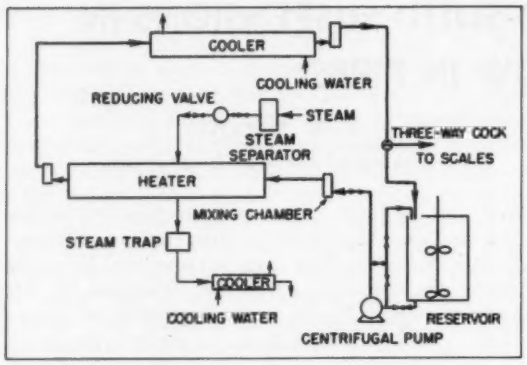

FIG. 1. SCHEMATIC DIAGRAM OF EXPERIMENTAL EQUIPMENT

enables one theoretically to determine the total resistance of the steam film plus that of a scale-free pipe by extrapolation to an infinite fluid velocity. Two basic assumptions are necessary for this treatment. One must assume that the fluid side resistance varies as the velocity to the eight-tenths power and that the resistances of the vapor film and pipe remain constant. The first assumption has been shown to be correct within most limits of experimental error provided that any changes in the physical properties of the fluid with temperature are corrected. The second assumption is discussed later, in the light of the experimental data.

The second method used to determine the heat-transfer coefficient has been to measure the pipe-surface temperature, and with this the value of the coefficient may be calculated directly. To measure the surface temperature, thermocouples usually have been placed directly on the surface of the pipe. Hebbard and Badger[6] have pointed out some of the more important requirements for the installation of pipe-surface thermocouples. In practice these requirements are difficult to meet, and several methods have been used with varying degrees of success.

In addition to the method of placement on the tube, the question arises as to where around the perimeter the thermocouples should be placed in order to measure the correct average temperature. Bromley[7] has shown that, with varying heat loads, no one place exists where a thermocouple may be placed to measure the correct average temperature. It is necessary, instead, to measure point temperatures at several places along the perimeter of the pipe and then average them by integration.

Apparatus

The apparatus used for this study consisted essentially of a horizontal double pipe heat exchanger with the auxiliary equipment necessary for measuring the various temperatures and flow rates. Figure 1 shows diagrammatically the layout of the apparatus.

The heater, which was modeled after one built by Kraft and Goldberg,[8] had an overall length of 8 ft. The heat-exchange tube was a horizontal standard 1-in. copper pipe with a length of 90¼ in. exposed to steam. The copper pipe was inside a 3-in. standard wrought-iron pipe which was enclosed in another 5-in. standard wrought-iron pipe. This pipe acted as an adiabatic jacket for the exchanger and prevented any heat loss except from the packing and flange connections from each side. Twenty-five ¼-in. holes were spaced evenly along each side of the 3-in. pipe, one-third the circumferential distance from the top. This provided sufficient area so that the drop in steam pressure from the outer to the inner annulus was negligible.

Available steam at 25-psi gage was reduced to 15-psi gage before passing through a separator to remove water. Small water coolers were placed on the condensate pipes to prevent flashing and evaporation. Chicksen ball-bearing swivel joints allowed the pipe to rotate so that the surface temperature distribution might be measured. Pointers connected to the pipe indicated the amount of pipe rotation. Pressure taps placed immediately before and after the heater were connected through flexible leads and a glass stopcock switching system to manometers filled with either mercury, ethylene dibromide, or methyl salicylate. A complete description of the pressure-drop system is given by Northey.[9]

In order to assure the correct measurement of the bulk temperatures, mixing chambers for the fluid were used. All temperatures were measured with copper-constantan thermocouples. Before being installed in the equipment, all thermocouples were calibrated against acetone and steam vapor and were found to agree with the Leeds and Northrup "38" calibration within the accuracy of the potentiometer used.

Two methods for installing the thermocouples on the pipe surface were used. The position on the pipe was the same for both methods. Considering the top of the pipe to be 0 degrees, and measuring angles counter-clockwise, thermocouples were installed in the pipe at an angle of 45 degrees, at 10¼ in., 47¼ in. and 84¾ in. from the entrance, and at an angle of 135 degrees, at 10¼ in., 47¾ in., and 85 in. from the entrance. Thus by rotating the pipe 45 degrees clockwise and 45 degrees counter-clockwise, the temperature could be read over a range of 180 degrees. Slots 1/16 in. wide and 1/16 in. deep were made on the pipe surface and thermocouple junctions were designed to fit these. The junctions were soldered in the slots, thus giving a pipe surface which was very nearly the same as before the installation of the thermocouples.

Experimental

Experimental runs were made with pure water, pure kerosene, water-graphite suspensions, and a kerosene-graphite suspension. For a given series of runs the inlet temperature to the heater was adjusted to give the same arithmetical average bulk temperature within 0.2° C for each run. At a given flow rate the temperature rise through the exchanger was noted. The inlet temperature was then adjusted by means of the cooling system to give the desired average temperature. The fluid was recirculated until equilibrium was reached.

The steam temperature was regulated for each run to give a temperature of 106° C. This was sufficient pressure to assure correct functioning of the steam traps. The flow rate was recorded by switching the flow into the weighing drum where the time required for the flow of about 100 pounds of fluid was measured with a stopwatch. Variation of temperature along any perimeter of the copper pipe was measured by rotating the pipe 10 degrees at a time.

Method of Calculation

A few runs using water were first made to check the experimental technique and equipment operation.

As mentioned earlier, two alternate methods can be used to calculate the h_s, and h_w, the steam-side film and water-side film heat-transfer coefficients, respectively. For runs where the pipe is rotated and temperature readings are available for various points at any one cross section of the pipe, an average pipe-wall temperature can be calculated. This enables the calculation of h_s and h_w directly, using the relationship,

$$h = q/A\Delta t.$$

Alternatively, Wilson's extrapolation method may be used.

During runs W-1 and W-6, circumferential surface-temperature distribution of the pipe was measured near the entrance, center, and exit end of the pipe by rotation. An average surface temperature for each of these positions was then obtained by integration (Fig. 2). Since the change in temperature along the pipe was less than 4° C, the temperature distribution was assumed to be linear, and an arithmetical average was used. The values of h_s and h_w calculated using this temperature are given in Table I.

A Wilson plot for these runs is given in Fig. 3. The best line for these data as determined by the least square method is represented by the following equation:

$$\frac{1}{U_o} = 0.000174 + 0.0000507 + \frac{1}{416V^{0.8}}.$$

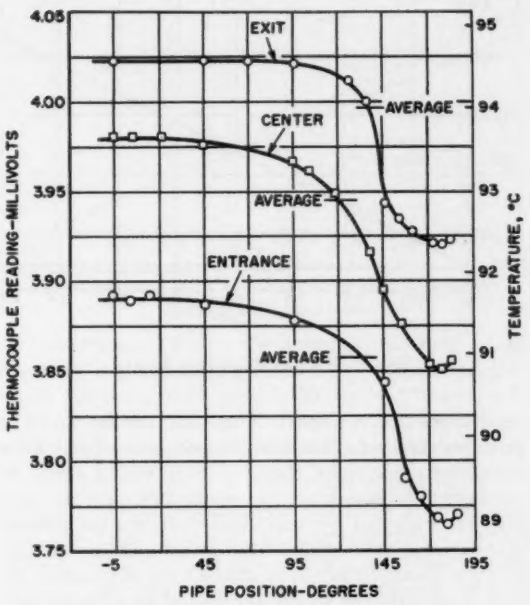

FIG. 2. CIRCUMFERENTIAL SURFACE TEMPERATURE DISTRIBUTIONS FOR RUN W-1

TABLE I

COMPARISON OF METHODS OF CALCULATION

Run No.	Surface Temp. Measurement		Wilson Method		Predicted by Nusselt
	h_s	h_w	h_s	h_w	h_s
W-1	6,680	2,940	5,730	3,050	1,380
W-6	6,600	1,452	5,730	1,491	1,650

The quantities on the right side of the equation are the steam-film resistance, the pipe resistance, and the water-film resistance, respectively. A comparison of h_s and h_w is given in Table I for runs W-1 and W-6 determined by the Wilson method, with values calculated from observed values of point temperatures on the pipe surface. In this table are also given values of h_s as predicted by the Nusselt equation. The Nusselt equation is good only for film-type condensation. It was found that steam contained small amounts of oil which would give rise to dropwise condensation, thus greatly increasing the heat-transfer coefficient. Moreover, since the runs were reproduceable within an average deviation of 4 per cent, this discrepancy between values predicted by the Nusselt equation and those obtained by experiment is not serious.

As discussed previously, when using the Wilson method one assumes that the steam-film and pipe

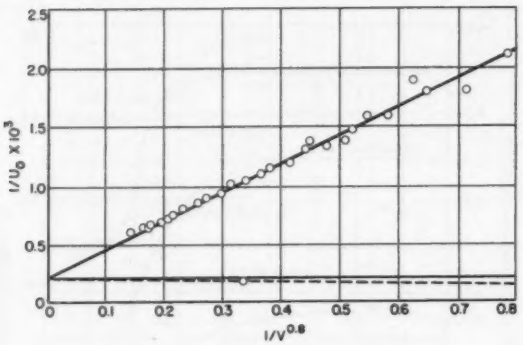

FIG. 3. WILSON PLOT FOR WATER

resistances are constant. This may not be so. The pipe resistance is less than 3 per cent of the total resistance and, since changes in it would result in negligible difference in the water-side resistance, it may be neglected for this discussion. In the present investigation the steam-film resistance is on the average about 10 per cent of the total resistance. At high flow rates the steam film would be a higher percentage of the total resistance, but it would also approach the value at infinite velocity where it is equal to the total resistance, neglecting the resistance of the pipe. At lower flow rates the error in the steam resistance would be greater than 30 per cent but it would then represent less than 10 per cent of the total resistance. Consequently the present error in the water resistance would be nearly constant for variable flow rates. The value of h_s calculated for run W-1 is 14.2 per cent higher than the h_s obtained from the Wilson plot. However, the h_w's show only a 3.3 per cent deviation.

On a Wilson plot, such as Fig. 3, the point representing the sum of the steam and pipe resistance as calculated from rotation run W-6 may be located. If a line drawn from the intercept at infinite fluid velocity and passing through this point is extended to a fluid velocity of 1 ft. per second, the indicated steam-film resistance is about 30 per cent lower than the intercept value. Since h_w is a function of the fluid velocity to the 0.8 power, a plot of U_o versus the velocity should vary from this slope if there is a variable steam coefficient. Such a plot of the water data has a slope of 0.69. Assuming the complete difference to be in the steam resistance, the resistance is 32 per cent lower at a fluid velocity of 1 ft. per second than at a fluid velocity of 10 ft. per second where the steam resistance approaches closely the Wilson intercept value. Finally, neglecting changes in physical properties of the steam film due to change in film temperature which would cause an error of less than 3 per cent, the Nusselt equation predicts that the steam-film resistance should be about 35 per cent lower at a velocity of 1 ft. per second than at 10 ft. per second. Therefore, a good estimate of the expected change in steam-film resistance may be obtained from the change predicted by the Nusselt equation.

When one desires to know only the water-film heat-transfer coefficient, the value obtained from a Wilson plot will usually be within experimental accuracy. Application of the above correction will allow for the change of the steam coefficient with varying amounts of heat being transferred. When the value of the steam-film coefficient is important, one should measure the true mean surface temperature by using a rotational procedure.

If the Nusselt correction is applied to the water data, the data on the Wilson plot may be represented by the following equation:

$$\frac{1}{U_o} = 0.000174 + 0.0000507 + \frac{1}{406 V^{0.8}}.$$

A comparison of the experimental water results with those given in literature shows the data to be about 30 per cent higher than those of Dittus and Boelter. However, they agree within 5 per cent with those of Jurgensen and Montillon[10] and of Bonilla.[11] This disagreement is not serious inasmuch as most investigators have observed considerable scatter. Some differences could be caused by the geometry of the experimental apparatus. Also, in many investigations, the thermocouples have been placed at the top of the pipe, which would result in lower values of the inside film coefficients.

Water-Graphite Suspensions

The values of the overall heat-transfer coefficients for the graphite-water suspensions are represented on the Wilson plot as shown in Fig. 4. As the same heat loads were realized for the suspension as for water, and the same overall driving forces were available, the steam-film coefficient should be the same. The same assumptions as were made with the water runs were made concerning the variable steam coefficient when the water-side coefficient was calculated. The best straight line drawn through the data may be represented by the following equations:

Suspension No. 1 (Graphite 5.85 wt %):

$$\frac{1}{U_o} = 0.000174 + 0.0000507 + \frac{1}{398 V^{0.8}};$$

Suspension No. 2 (Graphite 9.97 wt %):

$$\frac{1}{U_o} = 0.000174 + 0.0000507 + \frac{1}{357 V^{0.8}};$$

Suspension No. 3 (Graphite 13.48 wt %):

$$\frac{1}{U_o} = 0.000174 + 0.0000507 + \frac{1}{333 V^{0.8}}.$$

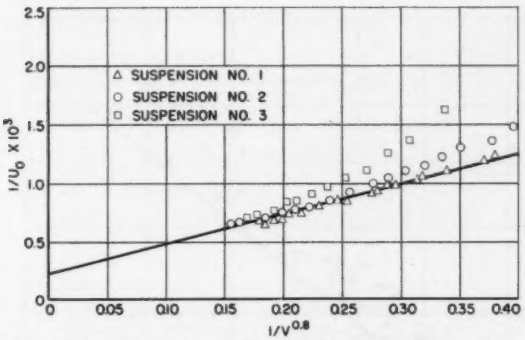

FIG. 4. WILSON PLOT FOR WATER-GRAPHITE SUSPENSIONS

Kerosene and Kerosene-Graphite Suspensions

The data for kerosene and kerosene-graphite suspensions are shown on a Wilson plot in Fig. 5. Since the steam film represents on the average only 3.5 per cent of the total resistance, any change in its resistance would have a negligible effect on the water-side resistance; therefore the Nusselt correction has not been applied.

The kerosene data may be represented by the following equation:

$$\frac{1}{U_o}=0.00012+0.0000507+\frac{1}{55V^{0.8}}.$$

For the kerosene suspension containing 4.73 (weight) per cent of graphite, the following equation may be written:

$$\frac{1}{U_o}=0.00012+0.0000507+\frac{1}{61V^{0.8}}.$$

A comparison of the experimental results for kerosene with the Dittus-Boelter equation shows that the agreement is nearly perfect. However, the data of Sherwood and Petrie[12] for kerosene are about 10 per cent above those predicted by the Dittus-Boelter equation.

Correlation of Data

While Wilson-type plots do allow one to determine individual resistances of heat transfer from experimental data, they do not lend themselves to a general correlation. If the premise made earlier that suspensions may be treated as homogeneous pseudoliquids is correct, at a constant DG/μ, h_iD/k should vary as $(C_p\mu/k)^{0.4}$. If the liquid in the film offers the controlling resistance to heat transfer, the assumption might be made that the particle has no effect on the thermal conductivity of the film and that the effective thermal conductivity is that of the suspending medium. A plot of the Nusselt-versus-Prandtl groups on this basis results in a straight line. As before, the data for the water suspensions fall 30 per cent above the general correlation. Therefore it appears that,

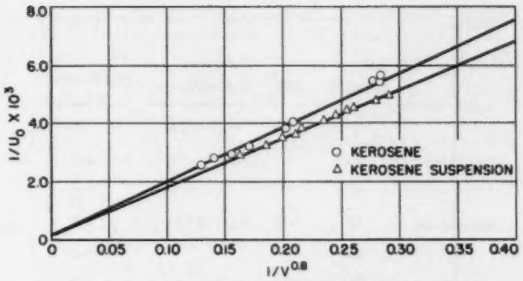

FIG. 5. WILSON PLOT FOR KEROSENE AND KEROSENE-GRAPHITE SUSPENSIONS

for suspensions where the thermal conductivity of the solid is greater than that of the suspending medium, the controlling resistance to heat transfer is in the medium, and the thermal conductivity of the solid does not appreciably affect the heat transfer.

A completely general correlation would allow for variation of the Reynolds number. Such a relationship has been obtained by plotting DG/μ versus $(h_iD/k)/(C_p\mu/k)^{0.4}$, as shown in Fig. 6. Close inspection of the data for water suspensions reveals that the suspensions have a tendency to fall below the curve at lower Reynolds numbers. Instead of having a slope of 0.8, the slope for the 13.5 per cent suspension at lower Reynolds numbers increases to greater than 1.0. This effect is usually noted for pure liquids which are not in turbulent flow, and would indicate that, in order to have true turbulent flow, the Reynolds numbers of the water suspensions must be higher than those usually expected for pure liquids. In the case of kerosene and kerosene-graphite suspensions, the data agree very well with the correlation. Since the viscosity measurement on the kerosene suspension showed it to be a true Newtonian fluid, one would expect the data to agree with the suspending medium data at lower Reynolds numbers than the pseudoplastic water suspension.

If, then, the Dittus-Boelter type of correlation is a correlation for suspensions in general, the data from other suspensions should also be correlated. The coal-water suspension data of Miller and Parks[13] and the calcium carbonate-water suspension data of Miller and Adams[14] were recalculated, using the thermal conductivity of the suspending medium. In order to correlate the data of Bonilla,[11] the viscosities had to be recalculated. This was done on the basis of relative viscosities as found by Miller and Adams.

Figure 6 is a general correlation on which all the available data for heat transfer to suspensions have been placed. The data may be represented within 15 per cent by the following equation:

$$\frac{h_iD}{k}=0.029\left(\frac{DG}{\mu}\right)^{0.8}\left(\frac{C_p\mu}{k}\right)^{0.4}.$$

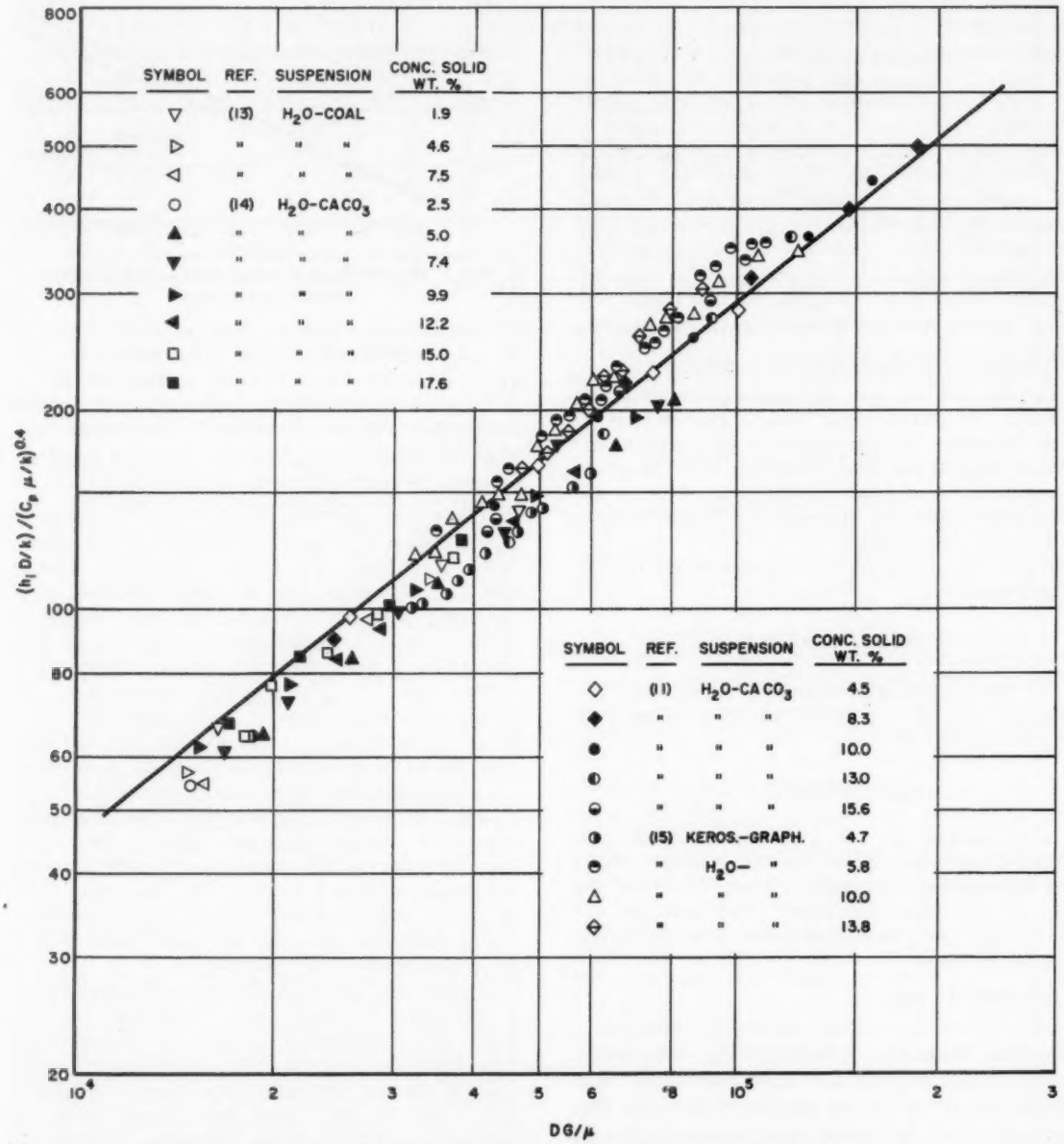

FIG. 6. GENERAL CORRELATION FOR HEAT TRANSFER TO LIQUUID-SOLID SUSPENSIONS

The above correlation has been realized using the apparent viscosity of the suspension, the average specific heats by weight, and the thermal conductivity of the suspending medium, all evaluated at bulk temperature. It may appear from the figure that a better representation of the complete data could be obtained by drawing a line with a slope of 0.9 instead of 0.8. However, if the data for each suspension are considered separately, they would preferably be represented by lines with a slope of 0.8. The average deviation of each suspension from its suspending medium is less than $\pm$ 10 per cent, which is considerably less than the usual deviation of $\pm$ 20 per cent obtained from a similar correlation for pure liquids.

NOMENCLATURE

A = Area of surface, sq ft.
C_p = Specific heat at constant pressure, Btu/(lb)(°F).
D = Inside diameter, ft.
G = Mass velocity, (lb)/(hr)(sq ft of cross section).
h = Coefficient of heat transfer between the fluid and surface, Btu/(hr)(sq ft)(°F); h_o is based on the outside area, h_i is based on the inside area of pipe.
k = Thermal conductivity, Btu/(hr)(sq ft)(°F per ft).
L = Length of straight tube, ft.
q = Rate of heat transfer, Btu/hr.
Δt = Temperature drop across the liquid film, °F,
U = Overall coefficient of heat transfer, Btu/(hr)(sq ft)(°F); U_o is based on the outside area of the pipe.
V = Average fluid velocity, ft/sec.
μ = Absolute viscosity, lb/(hr)(ft).
ϕ = Prefix designating a function.

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Seattle Host to Regional Metals and Minerals Conference

The Pacific Northwest Regional Metals and Minerals Conference of the AIME will be held in Seattle at the Olympic Hotel May 3, 4, 5. Papers dealing with the fields of mining engineering, metallurgy, petroleum engineering, and geology, as well as that of mineral industries education, will be featured in the program. Members of the University faculty will take a prominent part in many of the sessions, and distinguished representatives of industry, government, and other universities will present research findings and opinions. The following University of Washington members of the AIME appear on the program of the Conference as revised to date.

Dr. Earl C. Roberts, Associate Professor of Metallurgy, is chairman of the Physical Metallurgy Session. H. G. Anderson, student in Metallurgy, will report on "Studies of Iron-Chromium Alloys."

Dr. Harold D. Kelly of the Northwest Experiment Station on the campus (U. S. Bureau of Mines), will preside at the Industrial Minerals Session. Appearing on this program will be Dr. E. E. Mueller, of Ceramic Engineering, with "Requirements for Industrial Silica in the Northwest," and Kermit Bengston, research fellow in Chemical Engineering, who will speak on "Olivine."

Two members of the Geology Department, Dr. G. E. Goodspeed and Dr. Peter Misch, will present papers at the Geology Session, entitled "Granites of Magmatic Origin as Distinguished from Granites of Metasomatic Origin," and "Tectonic Patterns of the Western United States," respectively.

Professor Drury A. Pifer, Director of the School of Mineral Engineering, is chairman of the Education Session at which views from the college, high school, and industrial angles will be given. Dean of Engineering Harold E. Wessman will present "Trends in Engineering Education," and Professor E. R. Wilcox, of the General Engineering Department, will speak on "Freshman Engineering Education."

Professor F. B. Brien, of Mineral Engineering, is chairman of general arrangements for the Conference. Dr. J. I. Mueller, Professor of Ceramic Engineering, will supervise the X-ray diffraction equipment demonstration on the campus.

Industrial plant tours will round out the last session of the Conference, including among others, the Kaiser Gypsum Co., Seattle; the Pacific Car and Foundry Co., Renton; the American Smelting and Refining Co. and the Kaiser Aluminum and Chemical Corp., both at Tacoma.

Persons expecting to attend the Conference are urged to pre-register by mail, if possible. Registration in person will open at 4:00 p.m. Wednesday, May 2, on the mezzanine of the Olympic Hotel.

Washington Highway Commission members *(l. to r.)*: R. E. Hensel (Bremerton), O. E. Stone (Spokane), H. E. Morgan (Longview), E. C. Huntley, Chairman (Colfax). (R. A. Moisio, Tacoma, was not present.) Presiding Chairman *(extreme right)*, J. C. Gregory, General Manager, Automobile Club of Washington.

Road Builders Confer on Highway Problems

ENGINEERS, PUBLIC OFFICIALS, AND OTHERS, who met on the University of Washington campus, February 20-21, were principally concerned with what pending federal legislation would do to reduce street and highway deficiencies in the Pacific Northwest. They were also seriously concerned with the task confronting state and local administrations in providing the technical and financial co-operation which is necessary to qualify for the benefits of any new federal highway policy.

Well over two hundred visitors to the campus participated in this annual meeting which alternates between Oregon State College and the University of Washington. Eighty per cent of the registrants were from Washington, with the remaining twenty per cent coming from Oregon, Alaska, Montana, California, and the District of Columbia. Engineers predominated in the group, but a third of the registrants were public officials, suppliers, contractors, educators, and others. With respect to employer affiliation the registration breaks down as follows:

State	36%
County	14%
City	10%
Federal	9%
Private	31%

The Conference opened Monday morning under the chairmanship of Professor Martin Coopey from Oregon State College. Vice-President H. P. Everest, of the University of Washington, in welcoming the road builders to the campus, again pledged the co-operation of the University in an effort whereby its facilities could serve the administrators and users of Washington's roads and streets.

The keynote address was given Monday morning by R. H. Baldock, Oregon's nationally prominent State Highway Engineer, who discussed 1956 federal road legislation. Mr. Baldock reviewed past efforts to repair ever growing deficiencies in the nation's road and street systems. Pending legislation would authorize funds for building a national system of interstate and defense highways within 13 years at a cost of $27 billion. Other rural and urban federal aid systems would be granted additional federal aid totaling more than $2 billion in 13 years, in addition to the present annual authorization of $700 million. The federal share of this bill would be met by existing user taxes, supplemented by increased excises on fuel, rubber, and commercial vehicles.

Two major difficulties foreseen for any such augmented highway construction program are the growing shortage of trained engineers and the legal delays encountered in securing land for right-of-way. Robley Winfrey, Chief of the Personnel and Training Office of the U. S. Bureau of Public Roads, suggested that a highway engineering career would be more attractive, more remunerative, and more productive if graduate engineers were freed from routine duties through the employment of more sub-professional assistance. By this device one state cut in half the numbers of graduate engineers employed per

Panel members *(l. to r.)*: B. Lindman, Highway Economist, and M. E. Campbell, Highway Research Board, both of Washington, D.C.; H. E. Davis, Director, Institute of Transportation and Traffic Engineering, University of California. Presiding Chairman, D. C. Guilbert, Manager, Inland Automobile Association.

million dollars of construction program. The other bottleneck, delay in right-of-way acquisition, was discussed by the chief counsel of the Oregon State Highway Department, C. W. Enfield. He reviewed legal phases of this problem in Oregon and also in Washington, where a constitutional amendment at next November's general election offers the best hope for a way out of a very costly handicap.

The Monday afternoon session was devoted to discussion of the various factors which led to public reexamination of our traditional national road policy. While the dominant factor in seeking more money for roads is the need to relieve traffic congestion, A. F. Ghiglione, Commissioner of Roads for Alaska, pointed out that we must not forget that now, as in the past, some roads must be built to develop new land even before traffic itself becomes a problem.

B. J. McClarty, who is Secondary Roads Engineer for the U. S. Bureau of Public Roads in this region, raised the question of what level of improvement is economically justified for local rural roads, when funds are notably inadequate to meet estimated surfacing needs for low-traffic roads.

The critical need for suburban roads was given a fresh slant by Joseph Cohen, Assistant Professor of Sociology, University of Washington. Professor Cohen showed how the automobile has increased the effective radius of community circulation from 3 to 15 miles, so that our metropolitan areas have multiplied in size, more than in population.

This explosive suburban expansion has created problems in the city center. Seattle's city engineer, William E. Parker, described the difficulty faced by the city in attempting to alleviate urban congestion.

Most national discussion recently has centered upon the interstate system. Fred J. Dixon, District Engineer for the U. S. Bureau of Public Roads, at Olympia, explained the design standards selected for this 40,000-mile network of through highways.

Chairman of the Tuesday morning session was J. C. Gregory, general manager of the Automobile Club of Washington. The entire session was utilized to explain how state legislative and administration machinery works, since these state-level functions are essential to state participation in any increased federal highway program. E. C. Huntley, Chairman of the Washington State Highway Commission, introduced the other commissioners, and explained the nature of his organization. H. E. Morgan discussed the basic functions of the Commission. O. E. Stone told how the Commission transacts its business. R. E. Hensel reviewed the Commission's relationship with the public.

Senator W. C. Raugust explained how the Washington State Legislature handles road and street problems. During the past eight years a Joint Fact-Finding Committee of the Legislature has used the interim between biennial legislative sessions to investigate highway problems, to listen to local requests, and to make recommendations for highway legislation. These bipartisan committee reports have subsequently won legislative approval with impressive regularity; and the practice of log-rolling for road bills has been discarded.

W. A Bugge

R. H. Baldock

R. G. Hennes

W. C. Raugust

The final session of the morning was devoted to a step-by-step description of the creation of a new highway. The Washington State Highway Department has attracted favorable nation-wide comment during the administration of the present director, W. A. Bugge. Mr. Bugge outlined budgeting and programming procedures employed in his organization. R. H. Kenyon, Engineer of Plans and Contracts, then described how a project is brought up to the contract stage from the time it is put on the program. George Stevens, Bridge Engineer, explained how he dovetails his work with that of Mr. Kenyon. Finally, E. C. Simpson, Construction Engineer, discussed the work of the Department from the time the road contract is awarded to the time the highway is opened for traffic.

The final session of the Conference was held Tuesday afternoon under the chairmanship of David C. Guilbert, Manager of the Inland Automobile Association.

Three outstanding papers on current theories and present practice in the field of highway finance were read by a trio of nationally recognized experts: Harmer E. Davis, Director of the Institute of Transportation and Traffic Engineering, University of California; Bertram Lindman, Highway Economist, Johns Hopkins University; and M. Earl Campbell, Engineer of Economics, Finance and Administration for the Highway Research Board, Washington, D. C.

These three speakers serve also as consultants to an investigation being conducted for the Legislature by the Washington State Council for Highway Research into the equitable allocation of the costs of public roads and streets among the principal beneficiaries, i.e., the highway users, affected property owners, and the general public. Questions raised regarding various aspects of this inquiry were answered by members of the research staff responsible for the several subprojects involved.

The 1957 Conference will meet at Oregon State College, Corvallis, under the guidance of Professor Coopey. The present Conference was sponsored by the Department of Civil Engineering, University of Washington.

ROBERT G. HENNES
University of Washington

Life and Death of a Lake

(Continued from page 1)

A formerly famous Swedish resort, Lake Växjö, is reported as early as 1921 as being "no good except as a reservoir for city effluents" and as resembling "bluish-green soup," in contrast with other lakes in the region which, free from major effluents, have retained their color and sparkle.

At least 11 lakes in Finland have taken on eutrophic characteristics since comparatively recent times.

Striking closer home, are reports from the Yohara Lake Chain, Madison, Wisconsin.

Residents have complained vociferously about the esthetically repulsive blooms of blue-green algae which appeared concomitantly with the disposal of treated domestic sewage into Lake Monona about 1920. Eventually the sewage, together with the nuisance, was diverted downstream to Lake Waubesa. The public continues to be aggravated in spite of the use of copper sulphate to control the algal odors. The use of this chemical has brought additional problems owing to its highly toxic properties . . .

The abnormal acceleration of a process which is regarded as normal has had diverse effects, some of which are not for the best interests of man. The problem is especially serious because there is no way known at present for reversing the process of eutrophy. One thing is certain, that fertilization hastens the extinction of a lake, erasing it as a human benefactor. Unless some method can be discovered for oxidizing a large proportion of the additional deposits created by fertilizers, the lake's service to man is limited to a relatively short period.

Ceramic Engineering at the University of Washington: An Analysis

JAMES I. MUELLER
Professor of Ceramic Engineering

J. I. Mueller

Although the ceramic industry is recognized as one of the oldest in the world, and a ceramic plant was the first industrial plant to be established in the United States,* yet, prior to the 19th century, there was little exchange of technological knowledge in this field. All production methods were kept secret and nearly all plants operated on a "heritage of knowledge" basis. The works of Herman Seger and of A. Brongniart were the first to report the results of researchers in the field of ceramics. Edward Orton, Jr., a graduate of the Ohio Agricultural and Mechanical College (now Ohio State University), inaugurated the country's first formal educational program at that institution in 1894. Initially a two-year curriculum, it was expanded two years later into a full four-year program.[1]

Early Education in Ceramic Engineering

Ceramic engineering at the University of Washington was begun in 1918, with the appointment of Ira A. Williams as an assistant professor of ceramic engineering to the faculty of the College of Mines.[2] Williams left at the end of the school year after preparing the first curriculum (which was published in the 1918-1919 catalogue of the University) and partially equipping the laboratories. He was succeeded by Hewitt Wilson, through whose efforts the stature of the ceramic engineering department grew nationally. Even though twenty-one years had elapsed since Orton's pioneering efforts in Ohio, at the time of Wilson's arrival only six other universities were offering similar curricula. The following decade witnessed the establishment of instructional departments in six more institutions. These latter facts are significant because the United States has led the world in the development of engineers for the ceramic industry.

B. Butterworth, a British research chemist, in his book, *Bricks and Modern Research*, discusses the quality of published scientific papers by the ceramic societies in England, on the continent and in the U. S. He states:

> The *Journal of the American Ceramic Society* is the most consistent. This is because clay-workers in the U.S.A. have opportunities for a much higher standard of technical education than those in England. Many American Colleges have courses in ceramic engineering, and their graduates hold many of the responsible jobs in the industry.

He further quotes as follows from the Third Report of the (British) Committee on the Brick Industry:†

> Some indication of the technical outlook of an industry may usually be gained from the facilities available for general training, and from the extent and quality of its literature.... There is no chair of clay technology at a British University such as exists at several universities in the U.S.A., and organized courses of instruction in clay technology are few.

A total of 22 institutions in this country and Canada have offered degrees in ceramics or ceramic engineering. Of this number, 18 are currently active, of which 13 are accredited by the Engineers' Committee for Professional Development (ECPD). Until 1948-49, when ceramic engineering was inaugurated at the University of California on both the Berkeley and Los Angeles campuses, the department at the University of Washington was the only one on the Pacific Coast. As a result, many of the management and technical personnel in the industry on the coast received their education at this institution.

Growth in Enrollment

The total enrollment in this branch of engineering in the United States has never been high, the largest being recorded during the post World War II years. In 1949, for example, a total of 282 were graduated,[4] yet prior to 1940 there had been not more than a total of about 2,000 degrees granted. The undergraduate enrollment decreased quite sharply on a national level between 1948 (1086) and 1954 (501). The relatively small enrollment has never been due to lack of employment opportunities, but rather to a lack of understanding the potentialities of this field on the part of incoming freshmen students.

Gladding, McBean & Co., one of the Pacific Coast's largest producers of ceramic products, aware of this fact, in 1952 established two scholarships for incoming

* A plant for the manufacture of glass beads, used for trading with the Indians, was established near Jamestown, Virginia, in 1609.

† A committee established in 1941 to advise the Ministry of Works.

freshmen who intend to study ceramic engineering. Each scholarship carriers a yearly stipend of $350 and is renewable for four years. These scholarships, awarded each year and recently renewed by the Company for this year's high school seniors, amount to a total of $14,000 donated to date for this purpose. These scholarships have been a large factor in greatly increasing the enrollment in the Ceramic Engineering Division of the University during the past few years. They were the first of their kind to be established for ceramic engineering in the country, and the success of this program has led other corporations to set up similar programs at other institutions.

Another source of scholarship funds for freshmen ceramic engineers was established by the family and friends of the late C. A. Houlahan, former president of Builders' Brick Co. in Seattle and for many years an active industrial sponsor of ceramic engineering at the University. The C. A. Houlahan Memorial Scholarship Fund, established in 1955, provides a $100 scholarship to a member of the freshman engineering class who plans to major in ceramics.

The increasing diversity of uses of existing ceramic products and the greater requirements for and subsequent development of new products[5] has brought about a critical shortage of technically trained personnel in this field. In keeping with the demand, the enrollment in the ceramic engineering division at the University has doubled within the past two years, and the expected enrollment for 1956-57 will be nearly three times the average of the years 1949-1954 (Fig. 1).

It will also be noted from Fig. 1 that the ratio of graduate students to undergraduates is high, averaging nearly 1 to 3 through the years. This becomes even more significant when comparing the number of degrees granted in Ceramic Engineering. See Table I.

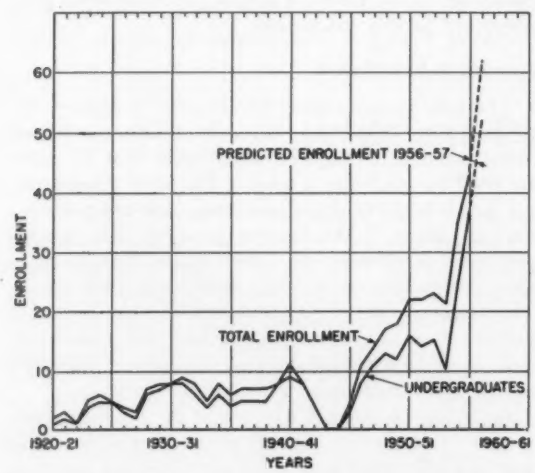

FIG. 1. UNDERGRADUATE AND TOTAL ENROLLMENT (including graduate students) IN CERAMIC ENGINEERING AT THE UNIVERSITY OF WASHINGTON

TABLE I

Degree	Year		Total No.
	1941 - 45	1946 - 55	
Bachelor of Science	37	36	73
Master of Science	24	29	52

Moreover, of the total of 52 receiving their M.S. degrees, six have earned a doctorate in ceramics or ceramic engineering and three are currently working towards their doctorates at other institutions.

It is significant that, of those receiving their M.S. degree, fewer than one-half have obtained their undergraduate training in ceramic engineering at the University. See Table II.

TABLE II

SOURCES OF GRADUATE STUDENTS

B.S. Cer. Engr., U. of W.	21
B.S. Cer. Engr., other institutions	20
B.S. other than Cer. Engr., U. of W.	6
B.S. other than Cer. Engr., other institutions	5
Total	52

From data available[6] for the academic year 1954-55, the ceramic engineering enrollment at this institution ranks fourth nationally in the number of undergraduates, fourth in the number of graduate students, and third in the total number of students. This compares with rankings of 13th, 5th, and 12th, respectively, in 1950-51.

Curriculum Development

Because of the lack of suitable textbooks and fundamental scientific data, the early course offerings in ceramic engineering were chiefly of a descriptive nature. This, coupled with the fact that the majority of the graduates were going to work in the ceramic industry (Table III), was responsible for pointing the curriculum in a highly specialized direction. It has been often stated by several educators in ceramic

TABLE III

EMPLOYMENT DURING FIRST FIVE YEARS AFTER RECEIVING DEGREE

Period	Degree	Ceramic Industry	Other Industry	School	Armed Forces	No Record
1925-30	B.S.	5	0	0	0	2
	M.S.	5	0	0	0	1
	Total	10	0	0	0	3
1950-55	B.S.	9	5	0	5	0
	M.S.	8	7	6	0	2
	Total	17	12	6	5	2

engineering that, whereas prior to 1940 nearly all of their graduates started to work in the ceramic industry, approximately 50 per cent of the graduates in the past several years are working with ceramic materials for non-ceramic industries. Data are lacking to substantiate this percentage on a national level, but the information from this institution presented in Table III indicates a definite trend in that direction.

This shift in field of employment has necessitated a change in curriculum over the years. Figure 2 indicates the percentage of credit hours in each subject area of the total hours required. The basic subject ratio is maintained at a fairly constant level throughout, with a gradual increase of requirements in English and the humanities, and of elective hours, at the expense of geology, mining, and metallurgical subjects.

Of greater significance is the change within the ceramic engineering offerings themselves. Whereas in 1928 only 18.7 per cent of these hours were spent on fundamentals and 41.7 per cent on instruction dealing with various ceramic products, the current curriculum apportions 42 per cent to fundamentals and only 11 per cent to products, half of which is devoted to the study of refractories—a product certainly of great importance to the ceramic and other industries. The rapidly widening scope of the ceramic industry and the variety of applications of its products[5] requires constant surveillance of the curricular offerings.

Research

The research in any field usually indicates the activity and growth of that field. A survey of research topics used for undergraduate and graduate thesis programs in ceramic engineering at the University (Table IV) shows clearly the areas of importance through the years. It is noted that during the first twenty years the emphasis was placed on raw material studies, which is understandable, since the development of the State's non-metallic minerals was of prime importance to this department.

Some representative M. S. thesis titles during the past ten years include the following:

Thermal Shock Resistance of Some Olivine-Clay Bodies
Hot Pressing of Low Fusion-Point Clay
Pacific Northwest Clays and Shales for Possible Use as Lightweight Aggregates
Reheat Load Test of Refractory Brick
A Study of the Fundamental Properties of Puget Sound Glacial Clays
Application of Fluid Mechanics to the Stiff Mud Extrusion Process
X-Ray Diffraction Intensities of Alpha Quartz
Development of a Test for Slag Resistance of Fireclay Refractories
Use of Olivine in Earthenware and Semi-Porcelain Bodies

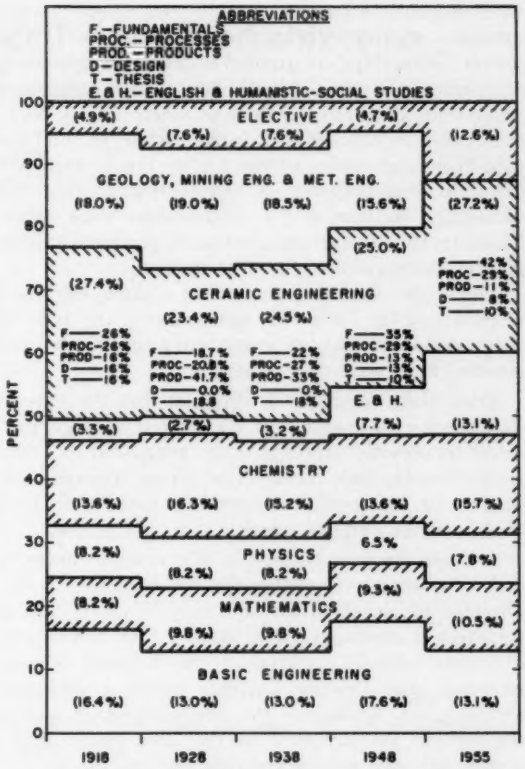

FIG. 2. SHIFTS IN THE CERAMIC ENGINEERING CURRICULUM AT THE UNIVERSITY OF WASHINGTON

TABLE IV

PER CENT DISTRIBUTION OF THESIS TOPICS
1920-1955

Year	Raw Materials	Processes	Fundamentals	Equipment Design	Other
1920-29	57	29	14	0	0
1930-39	53	32	10	0	5
1940-49	32	44	16	0	8
1950-55	31	31	16	14	8
Total	38	34	15	6	6

TABLE V

SOURCES OF FELLOWSHIPS IN CERAMIC ENGINEERING AT THE UNIVERSITY OF WASHINTGON
1920-1955

U. S. Bureau of Mines..... 28
Engineering Experiment Station..... 8
Edward Orton Ceramic Foundation..... 6
Gladding, McBean & Co..... 3

Also of interest are the sources of support for many graduate investigations (Table V). Chief among these are the co-operative fellowships with the Northwest Experiment Station, U. S. Bureau of Mines. These have been available to ceramic engineering students since the Division was started, and

were responsible for the large number of out-of-state graduate students during the years 1930-40. The Orton Fellowships are granted to ceramic engineering departments in the United States for investigation related to kiln-fired ceramic products. They were established by the will of Edward Orton, Jr., and are paid from the profits of the Orton Foundation, the principal manufacturer of pyrometric cones. The Gladding, McBean & Co. Fellowships were established in 1952 to further interest in graduate studies in ceramic engineering at this institution.

The scope of the employment of ceramic engineers is indicated in Table VI which shows the type of work done by ceramic engineering graduates employed in the state of Washington.

From these figures it is apparent that the state of Washington, although not considered a large producer of ceramic products when compared to Ohio, Pennsylvania, New York, New Jersey, Illinois, California, or Missouri, has certainly more than kept abreast of the national trend.

A challenge was thrown to the ceramic industry and educators two years ago by Maurice Nelles, Director of Research for the Borg-Warner Central Research Laboratory, who stated, "As a research executive who is engaged in the creation of new materials and devices for the future, I feel that ceramics will constitute the next important age in the world. We are now in the later phase of the metals age, and we are entering the ceramic age."

TABLE VI

CERAMIC ENGINEERS EMPLOYED IN WASHINGTON

TYPE OF EMPLOYMENT	1949		1956	
Ceramic Industry	16	(12)*	17	(12)
Management	3	(2)	3	(2)
Production	6	(4)	7	(4)
Research and Development	2	(1)	3	(2)
Sales	3	(3)	2	(2)
Consulting	2	(2)	2	(2)
Non-Ceramic Industries†	0		9	(7)
Education	2	(2)	3	(3)
Government Research	1	(1)	2	(2)
Total	19	(13)	31	(24)

* The figures in parentheses indicate the number employed in Seattle.
† All work in this bracket is in research and/or development.

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Motor Vehicle Courses Enjoy Continued Popularity

THE FIFTH ANNUAL MOTOR VEHICLE MAINTENANCE Conference was held March 19-21 on the University campus under the sponsorship of the College of Engineering in cooperation with the Automobile Club of Washington, the N. W. Section of the SAE, the Seattle Chapter of the National Association of Fleet Supervisors, the King County Safety Council, the Washington Motor Coach Association, and the Washington Motor Transport Association. A registration of 260 broke all previous records.

Representatives of manufacturers of automotive equipment came from as far away as Detroit and Louisville. Those from industries, city, state, and federal agencies, etc., while predominantly from the Seattle area included men from Oregon, California, Idaho, Montana, and British Columbia.

The informal panels were classified according to the size, type and use of equipment to be discussed, and dealt with specific maintenance problems concerned with transmissions, axles, tires, clutches, brakes, etc. The last session was a general discussion of shop practice, procedures, and operating problems.

THE 13TH ANNUAL COURSE for training supervisors of motor vehicle fleets was conducted April 2-6 on the campus by the University, the College of Engineering, and 25 cooperating state and national agencies. Professor Amos E. Neyhart, head of the Institute of Public Safety at Pennsylvania State University, was again in charge. Professor Neyhart, Consultant on Road Training for the AAA, acts in a like capacity for many large fleets throughout the United States. Session topics included "Good Drivers —How to Pick Them," "Training in Small Fleets and Large," "Supervision-Organizing for Smooth Operation," "Records—A Guide to Lower Costs," and "Creating and Maintaining Driver Interest."

At the close of the course certificates were presented to 36 "graduates" of the course in a joint meeting with the Seattle Chapter, NAFS.

Professor Fred H. Rhodes, Jr., of the Civil Engineering Department is the general director in charge of the three motor vehicle meetings held each year. The Training Course for Teachers of Driving will be held August 27-31.

Pressure Line for a Two-Hinged Arch Rib Subject to Vertical Loads

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P. H. Stern

Introduction

In the analysis and design of two-hinged arch ribs it is often desirable to find the "pressure line" for the structure under the given loading conditions. The shape of the ideal arch would be such that, for the given loads, the sum of the moments at any point equals zero, and the pressure line for the actual loading conditions therefore would represent this shape. In practice, however, it is impossible to design the shape of the arch so that the sum of the moments everywhere is zero, because, in general, the intensity of loading will vary during the life of the structure. Nevertheless a shape can be designed so that the moments for a given set of loads will be a minimum for critical loading conditions, although the designer may have to make several attempts at determining the shape of the arch before finding one to meet the desired conditions. Conversely, from a knowledge of the magnitude and location of the loads, the pressure line can be constructed, and by comparing the shape of the pressure line and the shape of the center line of the arch the magnitude of the moment at any point can be determined.

The method in this discussion is intended only for arches where the deflection of the arch due to the applied loads is small and will not affect the point of application of the loads. Hence, secondary effects may be neglected. The method has been devised as a tool for determining rapidly the ordinates of the pressure line for any set of vertical loads.

Derivation

The case treated here will be that of a two-hinged arch rib which is subjected to a known set of vertical concentrated loads, and whose reactions at the end points are known.

It should be noted that, while the arch shown here (Fig. 1) is loaded at equal intervals along the horizontal axis, the solution can be made perfectly general and applied to any set of concentrated vertical loads.

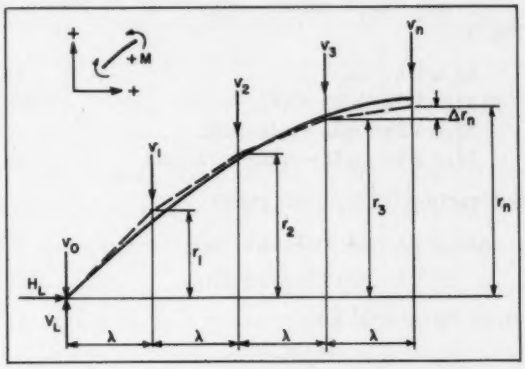

FIG. 1

The sign convention is as shown in the figure. Loads up and to the right are considered positive. The center line of the arch is shown as a solid line and the pressure line as a broken line. The subscripts refer to the panel point of the loads.

The moment at any point on the pressure line equals zero. Therefore,

$$\Sigma M_n = 0 = V_L(n\lambda) - H_L r_n - \sum_{i=0}^{n} v_i(n\lambda - i\lambda), \quad (1)$$

where

H_L = horizontal reaction at the left support,
V_L = vertical reaction at the left support,
v = vertical load,
λ = panel length,
r = vertical ordinate of the pressure line,
i refers to any intermediate panel point to the left of n,
n refers to the point under consideration.

Although any r_n can be determined from Eq. 1, this method involves a long and arduous process, especially when there are many panels. The following simplification is therefore introduced.

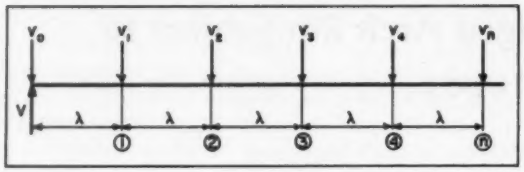

FIG. 2

For any beam simply supported, as shown in Fig. 2,

$$M_1 = V\lambda - v_0\lambda, \tag{a}$$
$$M_2 = V2\lambda - v_0 2\lambda - v_1\lambda, \tag{b}$$
$$M_3 = V3\lambda - v_0 3\lambda - v_1 2\lambda - v_2\lambda, \tag{c}$$
$$M_4 = V4\lambda - v_0 4\lambda - v_1 3\lambda - v_2 2\lambda - v_3\lambda. \tag{d}$$

Subtracting (c) from (d) yields

$$\Delta M_4 = V\lambda - v_0\lambda - v_1\lambda - v_2\lambda - v_3\lambda \tag{2}$$
$$= V\lambda - \lambda(v_0 + v_1 + v_2 + v_3), \tag{3}$$

or, in the general form,

$$\Delta M_n = V\lambda - \lambda \sum_{i=0}^{(n-1)} v_i, \tag{4}$$

$$\Delta M_{V_n} = \lambda\left(\Sigma F_v\right), \tag{5}$$

where

ΔM_{V_n} = change in moment at n due to vertical loads,

ΣF_v = sum of the vertical forces to left of the section considered.

Note that, although equal panel lengths were used for convenience, Eq. 5 is perfectly general, since it is simply another form of the well known relation:

$$dM = V dx. \tag{6}$$

Furthermore, Eq. 5 is true, regardless of the shape of the beam. This means that the beam may have any shape, as shown in Fig. 3.

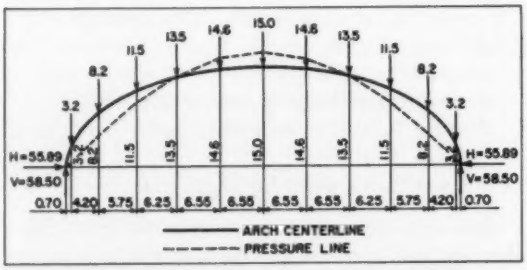

FIG. 4. ELLIPTICAL ARCH-RIB (span=60). See Table I.
(This problem is taken from *Statically Indeterminate Structures* by L. C. Maugh, page 218.)

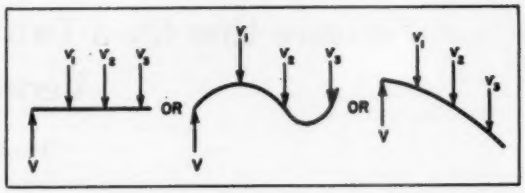

FIG. 3

Reasoning as in Eqs. 2 through 5 indicates that the change in moment at a point n due to the horizontal reaction H_L can be expressed by

$$\Delta M_{H_n} = \Delta r_n H_L. \tag{7}$$

Superimposing the results of Eqs. 5 and 7 and referring to Fig. 1 yields

$$\Delta M_n = \Delta M_{V_n} + \Delta M_{H_n},$$
$$\Delta M_n = \lambda\left(\Sigma F_v\right) + \Delta r_n (H_L). \tag{8}$$

Since by definition the moment at any point along the pressure line equals zero,

$$M_1 = 0,\ M_2 = 0,\ M_3 = 0,\ M_{n-1} = 0,\ M_n = 0,$$
$$\Delta M_n = M_n - M_{(n-1)} = 0,$$
$$\lambda\left(\Sigma F_v\right) + \Delta r_n (H_L) = 0. \tag{9}$$

Therefore, for the arch shown in Fig. 1,

$$\Delta r_n = \frac{\left[\sum_{i=0}^{(n-1)} F_v\right]\lambda}{H_L}. \tag{10}$$

The solution to Eq. 10 may then be presented in tabular form, which is shown best by a numerical example. See Fig. 4 with Table I and Fig. 5 with Table II.

Therefore,

$$r_n = \sum_{i=0}^{n} \Delta r_i. \tag{11}$$

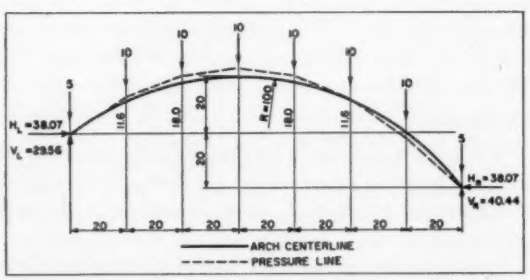

FIG. 5. CIRCULAR ARCH-RIB (span=140). See Table II.

TABLE I
(See Fig. 4)

Panel Point (x)	0	0.70	4.90	10.65	16.90	23.45	30.00	36.55	43.10	49.35	55.10	59.30	60.00
Δx	0	0.70	4.20	5.75	6.25	6.55	6.55	6.55	6.55	6.25	5.75	4.20	0.70
V	+58.50	−3.20	−8.20	−11.50	−13.50	−14.60	−15.00	−14.60	−13.50	−11.50	−8.20	−3.20	+58.50
ΣV	0	+58.50	+55.30	+47.10	+35.60	+22.10	+7.50	−7.50	−22.10	−35.60	−47.10	−55.30	−58.50
$\frac{\Delta x}{H}$	0	0.0125	0.0751	0.1029	0.1118	0.1172	0.1172	0.1172	0.1172	0.1118	0.1029	0.0751	0.0125
$\frac{(\Sigma V)\Delta x}{H}$	0	+0.731	+4.153	+4.846	+3.980	+2.590	+0.879	−0.879	−2.590	−3.980	−4.846	−4.153	−0.731
r	0	+0.731	+4.884	+9.730	+13.710	+16.300	+17.189	+16.300	+13.710	+9.730	+4.884	+0.731	0

Note: Sections for ΣV are taken just to the left of the panel point.

$\frac{(\Sigma V)\Delta x}{H} = \Delta r$. See Eq. 10.

Arrows indicate direction in which addition is performed.

TABLE II
(See Fig. 5)

Panel Point (x)	0	20	40	60	80	100	120	140
$\lambda = \Delta x$		20	20	20	20	20	20	20
V	+24.56	−10.0	−10.0	−10.0	−10.0	−10.0	−10.0	+35.44
ΣV	0	+24.56	+14.56	+ 4.56	− 5.44	−15.44	−25.44	−35.44
$\frac{(\Sigma V)\lambda}{H}$	0	+12.90	+7.65	+ 2.40	− 2.86	− 8.11	−13.36	−18.62
r	0	+12.90	+20.55	+22.95	+20.09	+11.98	− 1.38	−20.00

Note: $(\Sigma V)\lambda/H = \Delta r$. See Eq. 10.

$\lambda/H = \frac{20.00}{38.07} = 0.525$.

Arrows indicate direction in which addition is performed.

ACKNOWLEDGMENT

The writer is particularly indebted to Prof. A. L. Miller of the Department of Civil Engineering for the useful comments and encouragement he provided.

New Transportation Text Reviewed

(Continued from page 7)

aware of the importance of the railroads in the transportation problem, but thoroughly conversant with the problems of the industry. The first chapter deals with the history and present trends of the industry. The large number of tables that show the growth of the railroads and their relationship to the other forms of transportation are particularly valuable as they present the increase in gross tonnage, the change in the miles of track, etc., giving the reader an opportunity to judge the size and importance of this industry. The chapter on permanent way is well done, as is the chapter on turnout and yards, although perhaps more emphasis should have been given to the importance of sorting yards in the economical operation of railroads. The chapters on steam, diesel-electric, and electric locomotives cover the material adequately. In the chapter on diesel-electric locomotives the effect of the change from steam locomotive on the economy of operation is pointed out, and a number of curves and tables are used to illustrate the operating characteristics of this type of locomotive. The chapters on train resistance, and velocity and momentum grades are short; the reviewers would have liked to see these subjects given somewhat fuller treatment. The chapters dealing with the size and operation of trains and the economics of relocation are among the best in this section in that they show the relationship of what might be called the technical engineering feature of railroad engineering to the overall economic problem.

Part 4, River and Coastal Engineering, presents the engineering view and some economic factors concerned in the diverse structures employed to control water for the need of transportation. Among the structures discussed are channel protective works, locks and dams, ports and harbors, jetties, sea walls and wharves. Preceding each topic is a discussion of the natural phenomena involved. The treatment of waves is particularly noteworthy. Whenever appropriate, available analytical procedures are given. Care has been taken to include more than one design formula when the present techniques rely upon experimental and empirical values.

Part 5, which treats of pipeline transportation, is one of the minor sections of the text, consisting of only two chapters: Pipeline Transportation and Pipeline Construction. The first contains a large amount of statistical material in the form of tables, and several maps that help the reader to realize the magnitude of this type of transportation. It also discusses the factors that must be considered when a viscous material like oil is moved through pipelines. The pipe-friction treatment should, however, have been brought up to present standards. The second chapter deals largely with design procedures and some of the construction requirements.

Part 5 omits the transportation of natural gas, and, in view of the expanding network of natural gas pipelines, it seems that mention of this method of transportation would have been appropriate.

Part 6, the last section of the text, consisting of a single chapter, treats of transportation by belt conveyors. The authors point out the value of belt conveyors in the transportation of bulk commodities, and also mention that their most extensive use is in mining and heavy construction. One gathers from the text that at present no belt-conveyor system is in use as a common carrier. The chapter contains a number of tables and formulas for use in designing conveyor systems. One final paragraph in this section describes an interesting recent development in conveyor systems, namely, the passenger conveyor.

The text is adequately indexed, the reviewers finding no difficulty in locating any desired subject. The authors seem to have kept in mind at all times that the text is for the use of the neophyte, not the expert, in the field of transportation. They have struck a nice balance in theory, discussions, and illustrative material to produce an exceedingly teachable text.

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E. P. RICHEY
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NEW PROJECTS

Project No 197. Use of Models to Facilitate the Design of Hydraulic Structures. Sub-project I. Model Study of Nonuniform Flow over a Porous Screen. H. K. Moritz, Professor of Hydraulics, Supervisor; L-s. Miao, Research Assistant.

Project No. 198. Reaction Kinetics of Metastable Phase β in the Copper-Beryllium Alloy System. E. C. Roberts, Associate Professor, and D. Palonis, Assistant Professor of Metallurgical Engineering, Supervisors; D. M. Montgomery, Research Assistant.

Project No. 199. Ion Exchange Resins as Vapor Phase Catalysts. L. N. Johanson, Assistant Professor of Chemical Engineering, Supervisor; R. L. Kabel, Research Assistant.

Project. No. 200. Recovery of Carbon Dioxide by Stripping. M. M. David, Assistant Professor of Chemical Engineering, Supervisor; H. S. Glaze, Research Assistant.

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